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ESSENTIALS OF MEDICAL ELECTRICITY

A TEXTBOOK OF

RADIOLOGY

(X-RAYS)

BY

E. REGINALD MORTON

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ESSENTIALS
OF
MEDICAL ELECTRICITY

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PREFACE TO THE FIFTH EDITION

THE general plan of the present edition remains unchanged, but additions have been made to many of the chapters. In the treatment of disease of deep-lying organs, the mode of action of the constant current has been reconsidered in view of the prevalent belief that it is not possible to introduce ions far below the surface by the galvanic current. The properties and medical uses of the various currents have been more fully considered, and a short description of slow wave currents and three-phase currents has been added. The chapter on diathermy has been extended, and some notes have been added on the treatment of gonococcal infection by raising the temperature of the infected parts.

Experience gained in teaching an increasing number of students has revealed those parts of the study of medical electrology which present the greatest difficulties, and the opportunity has been taken, in preparing the present edition, to re-write many of the sections, in the endeavour to present the elementary and essential parts of the subject in as clear a light as possible.

E. P. C.

15, UPPER WIMPOLE STREET, W.

PREFACE TO THE FOURTH EDITION

THE present edition has been thoroughly revised, and many parts have been rewritten. The chapter on Medical Ionisation has been extended so as to include those diseases of women for which treatment by the ionic method is specially indicated.

The experience gained during the past two years on Diathermy has enabled a more complete account to be given of the uses of this important method of treatment in medicine and surgery.

The chapter on the Electrical Testing of the Reactions of Muscle and Nerve has been rewritten, and an account has been added of the physiological and pathological principles underlying the subject, so as to present a clearer explanation of the process of testing and the significance of the reactions observed. A further note on the use of Condensers in testing has been added.

The Tripier coil, the Water Rheostat, and the latest pattern of High-frequency apparatus have been described; and minor additions have been made to other chapters so as to bring the volume up to date.

E. P. C.

15, UPPER WIMPOLE STREET, W.
November, 1918.

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ESSENTIALS OF MEDICAL ELECTRICITY

INTRODUCTION

THE subject of the present volume is the use of electricity for the treatment of disease. Although the precise nature of electricity is unknown, its mode of action on the body is now more clearly understood, and it is being gradually recognised that its physiological and therapeutic effects are the consequence either of chemical or physical changes that it brings about in the tissues. The nature of these chemical and physical changes will be set forth in Chapter I. In many cases it is quite clear how electricity, by bringing about these changes, can cure disease or relieve its symptoms; in others it is less evident; but so long as we look upon the unknown agent electricity as an agent which produces known chemical and physical effects, we are enabled to see more clearly which diseases and morbid conditions are likely to benefit, and render less empirical their electrical treatment.

For the practice of medical electricity a sound knowledge of physics is necessary, for, without it, the principles of the subject and even the meaning of the terms in everyday use will not be understood, and it will be impossible to discover and put right simple failures of the apparatus when they occur. Those whose knowledge of physics has grown grey will find a brief outline of the physical principles of electricity and explanations of the terms in common use in Chapter XV.

With the exception of its use in testing the reactions of muscle and nerve, electricity deals almost entirely with treatment. Of the maladies for which it is used, there are some for which it produces cure or relief where other methods have failed, or where other methods are slower and less efficacious. There are other maladies, incurable by any known method, for which electrical treatment is still sometimes requested, cases which drift down, like derelicts, to the electrical departments of hospitals on the chance that some benefit may be derived there. There is a third group of maladies comprising the diseases of which the *symptoms* can be relieved by electrical treatment. For these, electricity is *part* of the treatment of the disease, and if it is to yield the best results, the general treatment should not be neglected. There is, now, no region of the body to which electrical treatment is not applied, and it is essential that the practitioner of electro-therapeutics should have a general experience of medicine as well as a special knowledge of the subject dealt with in the present book, while the prescriber should be acquainted with the field of medical electricity so that the treatment may be administered only to suitable cases.

CHAPTER I

THE MODE OF ACTION OF ELECTRICITY ON THE BODY

It has been mentioned in the Introduction that the physiological and therapeutic action of electricity is due to chemical or physical changes which it produces in the tissues. The way in which these changes are brought about will be best understood by the study of the passage of an electric current through water containing a salt in solution. If two wires leading from the poles of a battery are immersed in water without touching, and a milliamperemeter is placed in circuit, no current will be indicated if the water is perfectly pure and contains no salts in solution. The needle of the milliamperemeter will remain at zero. If now a salt, such as sodium chloride, is dissolved in the water the current is able to flow and the needle of the milliamperemeter moves across the scale. The addition of any other salt will produce the same effect, provided it is soluble in water. So also will a soluble base (such as sodium hydrate) or a soluble acid. These bodies, when dissolved, form solutions that enable the current to flow, and are known as "electrolytes." In the dry, undissolved condition they do not conduct the electrical current any more than the pure water, but in solution they undergo change, so that the current is able to pass. If, instead of a salt or base or acid, some albumen or other soluble protein, free from salts, is dissolved in pure water, no current will flow. If starch or dextrine or dextrose is dissolved, still no current will flow

Proteins and carbohydrates, and other chemicals such as alcohol and phenol do not, when they pass into solution, enable the electric current to pass : they are not electrolytes. The first important point to be observed with regard to the passage of the electric current through the body is this—the tissues conduct the electric current because they contain electrolytes —viz., salts in solution. The tissue protoplasm and its products are not themselves conductors of the current, but the latter can pass through them because they are permeated with fluid that contains salts in solution.

To return to the experiment on the passage of the current through the solution of salt. The passage of the current is not the only phenomenon observed. Chemical changes are at the same time taking place. One of these is evident. Bubbles of gas (hydrogen) are seen escaping in the region where the current is leaving the solution. Other chemical changes are taking place at the same time and will be mentioned in due course.

It is now necessary to consider more in detail the nature of these chemical changes and how they are brought about. When an electrolyte dissolves in water (thereby enabling the current to pass) it undergoes certain changes. It is generally believed that in the process of solution a certain proportion of the molecules divide or dissociate into two parts, each part taking an electrical charge. These electrically charged parts are known as " ions." Thus when a molecule of sodium chloride dissolves in water it divides into two parts, one, the sodium ion, bearing a positive charge ($\overset{+}{\mathrm{Na}}$), the other, the chlorine ion, bearing a negative charge ($\overset{-}{\mathrm{Cl}}$). The ions have properties quite different from those of the unelectrified atoms. A solution of sodium chloride contains sodium ions and chlorine ions, and in addition undivided molecules of sodium chloride. The ions take no particular course, but move about in any direction, sometimes reuniting with others, reforming the molecule, which again dissociates, and so on. When, however, an electric current flows through the soluton, the ions move in definite directions. Those with the positive charge (the sodium ions) move in the same direction as the current, and those with the negative charge (the chlorine ions) move in the opposite direction. This orderly movement of the ions is due to the following causes. The conductor along which the current *enters* the solution (known as the positive electrode or *anode*) is connected to the positive pole of the battery, and therefore the ions with the positive charge are *repelled* from it. At the same time they are *attracted* to the conductor by which the current *leaves* the solution (the negative electrode, or *kathode*), because this conductor is connected to the negative pole of the battery. The ions with the

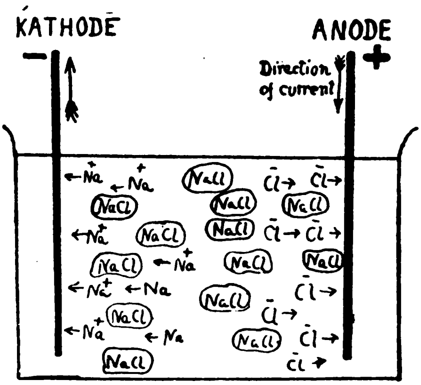

FIG. 1.—Passage of current through a solution of sodium chloride. Sodium ions migrating to kathode, chlorine ions to anode. Undivided sodium chloride molecules move in no definite direction.

negative charge make their way in a direction opposite to that taken by those with the positive charge, because they bear the opposite charge. The ions with the positive charge, therefore, travel in the same direction as the current " down-stream," while those with the negative charge make their way in a direction opposite to that of the current "up-stream." Those events are shown diagrammatically in Fig. 1. Now when the ions reach the electrodes to which they are attracted, their electrical charges are neutralised and further chemical changes occur. These depend on the nature of the ion and on the material of which the electrodes are made. Assuming that the electrodes are made of a metal like platinum, which resists corrosive action, the positively charged sodium ion reaches the kathode and its electrical charge is neutralised, whereupon the sodium, now in the free unelectrified state, regains the properties of free sodium and decomposes the water, forming sodium hydrate (caustic soda) and free hydrogen. The negatively charged chlorine ion reaches the anode and becomes free chlorine, some of which, in the nascent state, decomposes the water, forming hydrochloric acid and oxygen (Fig. 2). These are not the only changes that take place at the poles. It will be sufficient, at this stage of our inquiry, to say that bodies of an alkaline reaction form at the negative electrode (kathode). If red litmus is around this electrode it will turn blue. If the positive electrode (anode) is made of some metal that resists the action of acids, such as platinum, acids will be formed around this pole and can likewise be demonstrated by litmus.

The passage of the electric current through the solution, therefore, produces *two main changes*. In the first place, the ions *between* the electrodes of entry and exit of the current migrate in definite directions, those with the + charge migrating towards and accumulating at the negative electrode, those with the – charge migrating towards and accumulating at the positive electrode. There is therefore a redistribution of ions *between* the electrodes along the path of the current.

In the second place, new chemical bodies are formed *at* the electrodes.

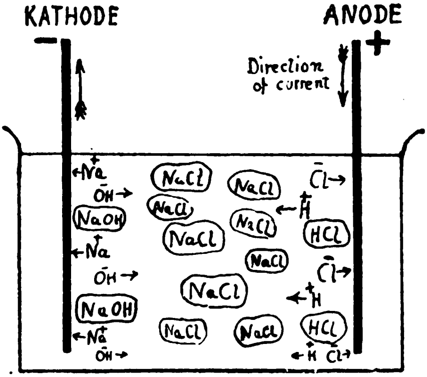

FIG. 2.—Passage of current through solution of sodium chloride. Sodium ions reach kathode and caustic soda and hydrogen (not shown) are formed. Chlorine ions reach anode and hydrochloric acid and oxygen (not shown) are formed. Some of the caustic soda molecules and hydrochloric acid molecules dissociate and form ions, viz., $\overset{+}{\mathrm{Na}}$ and $\overset{-}{\mathrm{OH}}$; and $\overset{+}{\mathrm{H}}$ and $\overset{-}{\mathrm{Cl}}$.

When a current of electricity passes through any part of the body, similar events take place. The tissue fluids contain many other salts besides sodium chloride—viz. carbonates, chlorides, phosphates, and sulphates of sodium, potassium, calcium, magnesium and iron, besides organic soluble salts, so that there are other ions as well as the sodium and chlorine ions. The two last-mentioned are, however, present in the largest number. The sodium hydrate which forms at the negative electrode has a caustic action on the tissue. So also has the hydrochloric acid which forms at the positive electrode. Either may be used for the destruction of tissue. This, the so-called electrolytic action of the current on the tissue, is really the chemical action of the caustic products formed at the electrodes. Here we have one of the examples of the mode of action of electricity on the body, by the production of *chemical* changes. The electrical current acts in this way when it is used for the destruction of nævi, warts, moles, etc., and the practical details of the method will be set forth in a later chapter. This method is sometimes spoken of as " surgical electrolysis " or " surgical ionisation."

There is, also, in the tissues, a migration of ions between the electrodes and a resulting redistribution. The conditions are more complicated in the case of the tissues that in the simple salt solution. There are various ions in the tissues and they are not in the same relative proportion or concentration in the various organs. Thus the tissues of the nervous system contain more potassium salts and phosphates, while the blood and lymph contain more sodium chloride and carbonate; that is to say, in the former there are more $\overset{+}{K}$ ions and $\overset{-}{PO_4}$ ions; in the latter, more $\overset{+}{Na}$ ions and $\overset{-}{Cl}$ and $\overset{-}{CO_3}$ ions. When the current traverses these tissues there must be some rearrangement in the relative proportion of the various ions in them. When, in cases of disease, the application of the electric current produces a beneficial effect, the mode of its action may be found perhaps in the migration and redistribution of the ions in the diseased part, some upset in the balance having possibly taken place in the disease, or possibly some new ions having been formed in the disease. It is, of course, very difficult in the present state of our knowledge to show the exact relation between ionic redistribution and therapeutic action. The following examples are suggestive as to the mode of action of the electric current by producing a redistribution of ions along the path of its flow.

(1) The constant current has the power to abolish the feeling of fatigue from a heavily worked muscle. This was spoken of as the "refreshing" action of the current. What probably happens is as follows. Fatigue products (perhaps sarcolactic acid or its salts) accumulate in the muscle. The passage of the current through the muscle causes migration of the ions of this acid or its salts, and many pass out of the muscle and into the blood vessels and lymphatics of the muscle, and are at once carried away by the circulating fluid.

(2) The refreshing effect produced by passing the constant current through the brain (cerebral galvanisation) is possibly due to a similar action, the removal of fatigue products as a result of the migration of their ions accompanying the passage of the current.

It is known, from physiological experiments, that alterations in the excitability and conductivity of muscle and nerve are caused by the passage of the galvanic current through these structures. In the region where the current enters (anode) there is a lowering of excitability and conductivity; the conductivity may even be abolished during the passage of the current. This altered condition is known as "anelectrotonus." In the region where the current leaves the muscle or nerve, there is increase of excitability and conductivity ("katelectrotonus.") In the intact body it is not possible to get anelectrotonus only, or katelectrotonus only, in any one region of the muscle or nerve. The reason for this is explained on p. 87. Anelectrotonus may be produced in excess of katelectrotonus, or vice-versa, and it is possible that the power of the galvanic current to relieve pain may be due to the production of anelectrotonus. The alterations of the excitability and conductivity of muscle and nerve are to be attributed to alterations in the distribution of the ions in these tissues caused by the current.

Another physiological property of the galvanic current is its power to cause dialatation of blood vessels. Erythema can be seen in the skin where traversed by the current, and it probably occurs in the underlying tissues on the path of the current. The power of the current to aid the absorption of exudation such, for example, as that which follows injury, may be due to the production of vaso-dilatation.

The power of the current to produce migration of ions can be utilised for a third purpose. If a solution containing ions is placed in contact with any part of the body and the current made to traverse the solution on its way through the body, the ions will migrate as previously described, so that some will pass through the skin into the body, and others, bearing the opposite charge, will pass in the opposite direction out of the body. The electric current can therefore be used for the purpose of introducing electrolytes (or, more correctly, their ions) into the body. A large number of drugs used in medicine are electrolytes. The current can therefore be used for the purpose of introducing drugs into the tissues, and the method is known as the " ionic method."

We have, therefore, three examples of the way in which electricity produces therapeutic effects by means of the chemical changes which it can cause These may be briefly re-stated :

1. *The production of new chemical bodies at the electrodes of entry and exit of the current into and from the body.* These bodies have a caustic action, and are used for the destruction of diseased and unnecessary tissue. The process is known as " surgical ionisation."

2. *The rearrangement of ions along the path of the current through the tissues.*
3. *The introduction of new ions from without.* The process is called " medical ionisation," and the method is known as the " ionic " method.

The changes mentioned under 2 and 3 are on the border-line between chemical and physical; they may be called physico-chemical.

While the current is passing through the body it stimulates the excitable tissues, as indicated by the subjective sensations produced, such as pain, the feeling of burning and pricking. These sensations are in all probability the result of the migration of ions through the sensory nerves and end-organs. If the current flows in the same direction and with strength unvaried, no muscular contraction is noticed. The migration of the ions stimulates sensory nerves, but not motor nerves or voluntary muscle. If, however, the migration of the ions is suddenly stopped by switching off the current, the muscles give a single twitch at the moment the current is interrupted. A single twitch is also noticed at the moment when the current is switched on again, and the migration of the ions again suddenly started. An abrupt start of ionic movement or cessation of movement is therefore necessary if voluntary muscle is to be stimulated to contract. The former happens to be a more effective stimulus than the latter, so that the twitch occurring at the moment when the current is switched on (the so-called " closure contraction ") is larger than that occurring at the moment when the current is switched off (the " opening contraction "). Other tissues, besides muscle and nerve, are, in all probability, stimulated, and the beneficial action of electricity in the treatment of certain conditions (of whch *paralysis* may be mentioned as one) is not to be attributed to any mysterious or vital action of the electricity, but rather to the stimulation of the tissues produced by the ionic movement that is a necessary accompaniment of the passage of the electric current.

Just as a sudden movement in the same direction or sudden cessation of movement of ions will cause a voluntary muscle to contract, so will a sudden *reversal* of their movement. If the reversal is *slow,* the current slowly sinking to zero and then rising to its maximum with equal slowness, but in the opposite direction, there will be no contraction of muscle, but a sensation of smarting and pricking will be perceived, because the slow to-and-fro movement of the ions acts as a stimulus to sensory nerves, but not to voluntary muscle or motor nerves. If the reversal of the current becomes more frequent, the ionic oscillation will become sufficiently frequent to stimulate motor nerves and muscle, and contraction will occur. With a still greater frequency of current reversal and ionic oscillation, all sensation will disappear, except that accompanying the contraction of the muscles. Finally, when the frequency of the current reversal becomes extremely high—a million or more reversals taking place each second (this is the so-called " high-frequency " current)—there will be no contraction of muscles and no stimulation of nerves, and there will be no chemical change of any kind.

This inability of the high-frequency current to produce the physiological phenomena that are brought about by the constant current or the current that oscillates with a lower frequency had, for many years, received no satsfactory or intelligible explanation. But if the phenomenon is considered in the light of the behaviour of the ions that accompanies the flow of the current, and the electrical stimulus regarded as a sudden ionic movement, it receives a satisfactory explanation. If the current travels to and fro with a frequency of a million or more per second, the ions are unable to keep pace with it : they remain stationary, and there is no ionic movement. During the millionth part of a second for which the current is flowing in any one direction before it reverses, the ions have been unable to move, or at any rate, to move sufficiently to bring about a stimulation of excitable tissues. Now that it is possible to pass an electric current through the body without stimulating the excitable tissues, and without producing chemical change, we are able to utilise electricity for the production of heat within the body. Since the high-frequency current does not stimulate the excitable tissues, it may be passed through the body in strength for greater than that permissible for constant or low-frequency currents, and it will then develop heat on its path through the tissues as it overcomes their resistance. The constant current or low-frequency current are unable to act in a similar way, because they would produce violent muscular contraction and unbearable pain long before they reached a strength sufficient to develop heat. The heat that is generated by the high-frequency current is developed *on the path along which it flows, so that the deep-lying tissues are heated as well as the superficial.* The raising of the temperature of the deep as well as the superficial tissues is known as "diathermy." It forms an important branch of medical electricity, and is described in Chapter XII.

High-frequency currents were used in medicine for many years without a clear knowledge of the way in which they produced their physiological and therapeutic effects. The recognition that these results were due to the development of heat within the tissues and organs showed that the high-frequency apparatus then in use for medical purposes was not suitable for the production of much heat. The modern diathermy apparatus has since been evolved with this end in view—viz. the generation of the largest quantity of heat.

The development of heat within the tissues by the high-frequency current is an example of the other mode of action of electricity on the body—viz., by the production of *physical* effects. The physical effect is, in this case, the development of heat. In the case of the constant current and the currents of low-frequency oscillation, the effects are chemical or physico-chemical, and are brought about through the agency of ionic movement; in the case of the high-frequency current the effects are thermal and the ions are not moved.

Electricity can produce chemical and thermal effects in another way, quite different from that already described. The static breeze and high-frequency effluve will illustrate this. These forms of electrical application will be described later, but here it may be said that electricity at a very high potential is applied, so that if an air-gap is inserted between the electrode and the patient's body, the electricity, if directed from a pointed electrode, is able to bridge the gap in the form of a non-luminous brush, scarcely visible except in the dark. The application of this brush to the skin strongly stimulates the latter. The stimulation is due most probably to the *heating* of minute points of skin. Erythema is produced and even urticaria, if the application is strong. We are able, in one instance at any rate, to trace the physical, physiological and therapeutic results of the application of electricity. A patient suffers from headache as the result of low blood pressure. The application of the static breeze induces an erythema by the heating of minute points of the skin, and, as a physiological result of peripheral stimulation of the sensory nerves, there is a reflex rise of blood pressure and the headache disappears.

The passage of the brush discharge through the atmospheric gases causes the formation of ozone and higher oxides of nitrogen. It is probable that these chemical products play a part, by virtue of their germicidal action, particularly in the treatment of some skin affections and infected ulcers.

The application of sparks from a static machine will frequently relieve pain in the region of muscles and fasciæ—*e.g.* the lumbar region—and the relief is sometimes instantaneous. The mode of action of electricity in such cases is, most probably, *mechanical.* The sudden powerful muscular wrench that accompanies the passage of a long spark breaks down adhesions. The current known as the "static wave current" also produces rhythmic muscular twitches, but less violent and more agreeable than those produced by the sparks. In bringing about relief, as it often does, in certain cases of chronic inflammation and congestion (*e.g.* traumatic synovitis, chronic neuritis, etc.), electricity, in the form of the static wave current, produces its results by physical (mechanical) methods. In applying the static wave current (the details will be given later) the body is alternately charged and discharged, the electricity suddenly escaping, during discharge, by way of an electrode placed in contact with the part requiring treatment. The therapeutic results are to be attributed, not directly to the electricity, but rather to its power of producing physical (mechanical) changes, the rhythmic twitching of the muscles inducing local acceleration of the circulation and mechanical removal of the effusion and loosening of adhesions.

The galvanic current also possesses the power to cause a movement of water in a conductor along which the current passes. The movement takes place from the anode to the kathode, and can occur through permeable membranes and against the force of gravity. A semi-solid block of gelatine, when traversed by the current, becomes dryer under the anode and moister under the kathode, owing to the passage of water in the direction of the current. This movement is known as *kataphoresis* or *electric osmosis*. It is possible that it may play some part in the absorption of pathological exudations. It was formerly thought that the entry of ions through the skin was due to kataphoresis.

When the galvanic current traverses a fluid containing micro-organisms in suspension, the latter migrate towards the anode. It is likely that this movement takes place when the current is directed through infected fluids, and if the organisms can reach the anode they will be destroyed. When the urethera is infected by gonococci, the organisms migrate from the small lacunæ in the epithelium where they are inaccessible to irrigating lotions, and move to an electrode (anode) placed in the channel. Leucocytes containing injested organisms also migrate in the same direction. A method based on this principle is used by Dr. Charles Russ for clearing the urethera of gonococci.

It is not pretended that the account given in this chapter of the mode of action of electricity will explain, in every case, the way in which disease responds to electrical treatment. But if we look upon the cure or relief of disease by electrical methods as due, not directly to the electricity itself, but rather to known chemical or physical changes that it produces, we are better able to judge whether electrical treatment is suitable for a case, and foresee the results that may be expected from its application

CHAPTER II

THE VARIOUS ELECTRIC CURRENTS USED IN MEDICINE

THE various methods of applying electricity for the treatment of disease are, to all outward appearance, very dissimilar, as will be apparent to one who visits a modern electrical clinic. Yet in the greater number of cases an electrical current is applied, modified, in one way or another, and producing different physical and physiological effects. Each current may be derived, directly or indirectly, from one source—that is, the constant current. In this chapter it is proposed to describe the various modifications of the electrical current, taking the constant current as the starting-point.

THE CONSTANT CURRENT

This current is so called because its strength does not vary and its direction of flow does not change. It is sometimes called the "continuous current," sometimes the "galvanic current." The constant current supplied on the main in certain districts is generally called the "direct current," or, for short, D.C.

Source of Constant Current.—The constant current may be obtained by *chemical* action, such for example, as that which takes place in a battery cell or accumulator, or by *mechanical* action, as in the revolution of the armature of a dynamo. A description of battery cells and of the dynamo will be found in Chapter XV., which deals with Physical Principles.

Measurement of the Constant Current.—This current can be accurately measured. When it is used for medical purposes its strength should always be measured. For domestic and commercial purposes, the unit of strength is the *ampere*. For medical use, the unit is the *milliampere,* i.e., a thousandth part of an ampere, and the measuring instrument is known as the *milliamperemeter.* A description of this instrument will be found on p. 366.

Properties and Uses of the Constant Current.—There have been considered in the previous chapter, and here they will be summarised. The current is able to cause ions to migrate, and can, therefore, be used for the purpose of introducing ions possessing therapeutic properties into the body. This form of treatment, known as *Medical Ionisation,* is described in Chapter V. The current is able to cause the formation, in the tissues, of caustic chemical substances, which have the power to destroy abnormal tissue. This form of treatment, known as *Surgical Ionisation,* is described in Chapter VI. The current is able to cause migration of the ions present in the tissues. Accompanying this migration (and probably due to it) are certain *physical* phenomena, viz., movement of water in the direction of the current (kataphoresis) and movement of bacteria in suspension towards the anode; and certain physiological phenomena, such as alterations in the excitability and conductivity of muscle and nerve (katelectrotonus and anelectonus) and vaso-dilatation. The precise relation and connection between these charges and the other therapeutic effects of the constant current is not known with certainity, and the use of the current for the treatment of some maladies is empirical. Speaking generally, it may be said that the constant current is able to relieve pain due to neuritis and to aid the absorption of inflammatory exudation, particularly that due to injury.

The use of the constant current for purposes other than the introduction of ions or the destruction of tissue will be considered in Chapter VII.

Electrical currents may be modified in various ways. They may be periodically interrupted, with or without reversal, frequently or infrequently; and the rate at which the current increases from zero to maximum, after interruption, may be slow or rapid. These current possess the power to stimulate tissue. Some are more suitable for some tissues and certain morbid conditions than other. The methods of producing them, and their properties and uses, are described below.

SIMPLE INTERRUPTED CURRENT

This current flows always in the same direction, but the flow is *intermittent,* not continuous. There are alternate periods of flow and no-flow. During each period of flow the current strength is constant. At the end of this period the flow ceases *suddenly,* and the period of no-flow follows. At the end of the latter period the flow is *suddenly* resumed. A graphic record of a simple interrupted current is shown in Fig 3. BC represents a period of flow, DE a succeeding period of no-flow. CD represents the sudden cessation of the current, EF its sudden resumption. The height of the line above the base-

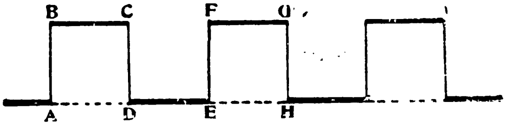

FIG. 3.—Graphic representation of simple interrupted current. The periods of current-flow and periods of no-flow are, here, of the same duration.

line would be proportioned to voltage or amperage; the distance along the base-line would indicate time intervals.

Production of Simple Interrupted Current.—This current can be produced by alternately making and breaking the circuit along which the current flows. This can be effected by various mechanical devices. A simple make-and-break key can be introduced into the circuit and operated by hand. A metronome can be adapted (Fig. 4), so as to produce regular and even interruptions. The swinging arm bears a horizontal wire, to each end of which is fixed a short vertical wire. Another vertical wire of equal length is fixed to the centre of the horizontal piece. When the arm of the metronome swings to and fro, the horizontal wire moves with it, and the vertical wires at the extremity of the latter rise and fall. Three small cups of mercury are fitted to the metronome, and so arranged that as the vertical wires fall and rise they dip into and rise out of the mercury in the cups. The central vertical wire does not rise or fall, but stays permanently immersed.

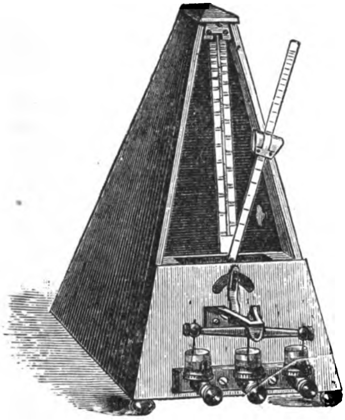
FIG. 4.—Metronome Interrupter.

The vertical wires that dip into the mercury should be made of silver. A terminal is connected to each cup. To use the metronome as a current interrupter, one end of the wire conveying the current is attached to the central cup, the other end to one of the end cups. When the wire rises out of the mercury the current is interrupted. The number of interruptions per minute will depend upon the rate of swing of the metronome. The time the current flows between each interruption depends on the rate of swing of the metronome and the depth to which the wires dip into the mercury. The metronome can be used in the following way to interrupt two currents alternately. Of the wires conducting the second current one is connected to the other end cup, the other wire to the central cup.

The metronome interrupter may be used when regular interruptions of a current are desired without accurate measure of their duration. The interruption is relatively infrequent and the periods of flow and interruption are relatively long.

Another device for procuring simple interruption of the constant current is Leduc's mechanical interrupter. By means of this instrument the current may be interrupted as frequently as desired, and the periods of flow and of interruption may be varied and accurately measured. They can be made extremely brief, if desired.

Leduc's Mechanical Current Interrupter.—The essential part of the apparatus is a disc of insulating material mounted on the axle of a small motor and rotating with it (Figs. 5 and 6). Four metal strips are secured on the circumference, each being of equal length. They are placed symmetrically around the circumference. There is a small interval between consecutive strips. Diametrically opposite strips are in metallic connection with each other. Two contact brushes press against the circumference of the disc, one being fixed, the other being movable through an arc of 90°, so that it may touch the circumference at a point diametrically opposite the fixed brush, or at any point nearer. It should not approach closer than one quarter of the circumference. The current can pass from one brush to the other, as long as the brushes are in contact with diametrically opposite pairs of strips. When the brushes are in the position shown in Fig. 5 (continuous lines), the current can flow from one strip to that opposite, and continue to flow, when the strips are revolving, for the longest time possible. But when the movable brush has been moved round through 90° the current can flow only for the shortest time. In the first position the current flows for the longest time and the period of no-flow is the shortest. In the second position the period of flow is the shortest and that of no-flow is the longest. Intermediate positions of the brush give other periods of flow and no-flow. Increase of the length of the time of current-flow shortens the period of no-flow, and *vice versa*. The number of interruptions of the current depends upon the speed of

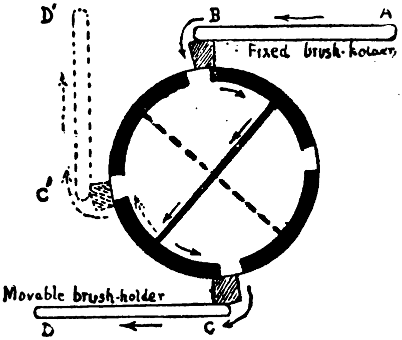

Fig. 5.—Plan of commutator of Leduc. When the current flows from the fixed brush-holder AB to the movable brush-holder in the position CD, the period of current-flow is the longest and of no-flow the shortest.

When the movable brush-holder is in the position C′D′, the period of current-flow is the shortest and of no-flow the longest.

revolution of the disc. The number of revolutions per second can be measured by a speed indicator. Increase of the speed of the interrupter will shorten the periods both of flow and no-flow.

By means of this current interrupter it is possible to vary the number of interruptions and measure the duration of the period of flow of the current, and the period of no-flow. The interrupter is shown in Fig 6.

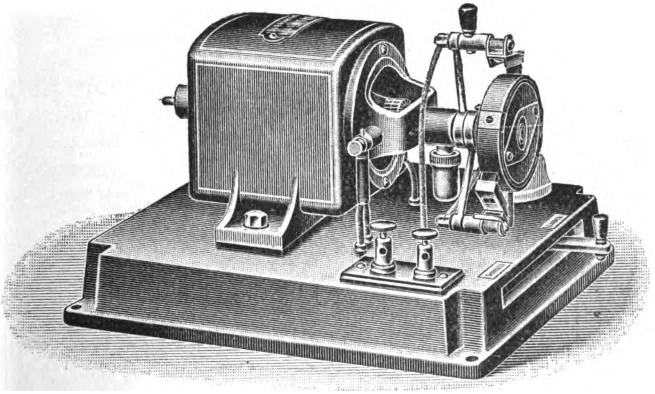

FIG. 6.—Leduc's Mechanical Interrupter.

Measurement of Simple Interrupted Current.—The strength of this currrent can be measured by means of an amperemeter included in the circuit, the latter being closed by stopping the interrupter. When the strength is noted, the amperemeter is taken out or short-circuited by means of the shunt usually fitted to it. The rate of interruption can be counted if the metronome is used. The duration of flow and of no-flow can be measured only by special apparatus. In the case of the Leduc interrupter, the frequency of the intermission is measured by a speed indicator and the duration of the periods of flow and no-flow can be estimated from it.

Use of the Simple Interrupted Current.—This current is used for the stimulation of the tissues, particularly muscle and nerve. When the current is very frequently interrupted by means of the Leduc apparatus, it has the power to stimulate the central nervous system, but it has not yet been used for this purpose in medicine.

SIMPLE ALTERNATING CURRENT

This current differs from the simple interrupted current in that it flows, during successive periods, in opposite directions. A graphic record of such a current is shown in Fig 7. Between the successive periods of current-flow there are periods of rest, so that the current is *intermittent* as well as alternating. At each period of flow the rise of the current to maximum and its fall to zero are sudden.

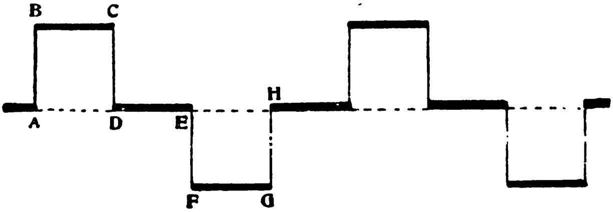

FIG. 7.—Graphic representation of a simple interrupted and alternating current. The periods of current-flow are here equal to the periods of no-flow.

Production of Simple Alternating Current.—The simple alternating current may be obtained from the constant current by means of a special reversing metronome (Fig. 8). It has four mercury cups. Two terminals are provided for connection to the source of the current, and two others for connection to the patient. When the swinging arm is on one side the current flows in one direction to the patient, and when it is on the other side the direction of flow is reversed. Some reversing metronomes are made so that they can be converted into simple interrupters by moving a switch.

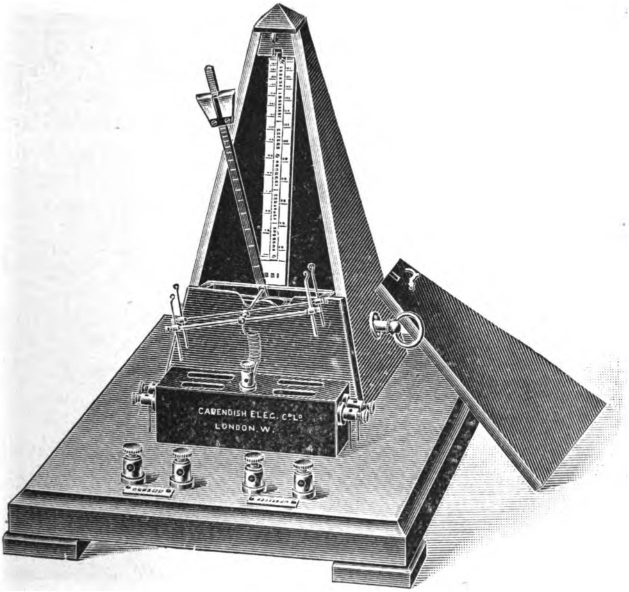

FIG. 8.—Reversing Metronome.

Measurement of the Simple Alternating Current.—This current can be measured in the same way as the simple interrupted current.

Uses of the Simple Alternating Current.—This current is used for the stimulation of the tissues, especially muscle and nerve in cases of paralysis when the muscles show the reaction of degeneration.

SINUSOIDAL ALTERNATING CURRENT

The sinusoidal current is an alternating current, but it differs from the simple alternating current just described, in that its rise from zero to maximum and its fall from maximum to zero are gradual, not sudden. Further, on reaching zero, there is no period of intermission, but a second rise to maximum and fall to zero, in the opposite direction. A graphic representation of a sinusoidal current is shown in Fig. 9. From A to B the current is rising to its maximum; from B to C it is falling to zero; from C to D it is rising to a maximum again, but the current is flowing in the opposite direction; from D to E it is falling again to zero. ABCDE represents a complete cycle or *phase*. The

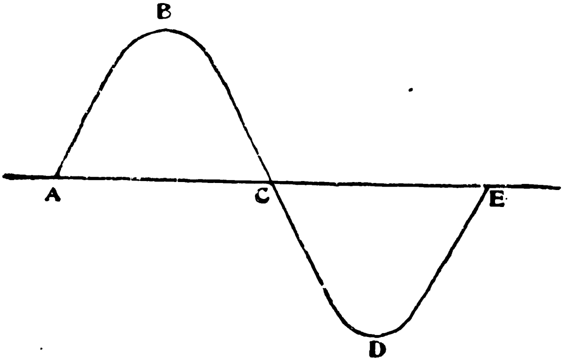

FIG. 9.—Graphic representation of a sinusoidal current—one complete phase.

"periodicity" of the current refers to the number of these complete cycles per second. If the current has a periodicity of 100, there are 100 of these cycles each second. From A to E the time interval would be 1/100th second; from A to C 1/200 second. The height of the curve above the base-line at any spot is proportioned to the voltage or amperage. The current is called "sinusoidal" because its graphic record is approximately a sine curve.

Sources of Sinusoidal Current.—In certain districts the current supplied on the main is a sinusoidal current, or as it is named commercially "alternating current," or, for short, AC. If, however, a *direct* current is supplied it may be converted into a sinusoidal current by means of a machine known as a "motor transformer," "motor generator," or "rotary converter." Makers of electro-medical apparatus now put on the market different patterns of so-called "universal" apparatus, sold under the trade names of "Pantostat," "Multostat, "Polystat," "Plurostat," etc., and these convert constant into alternating sinusoidal currents. Such instruments are now largely used, and one pattern is illustrated in Fig. 10.

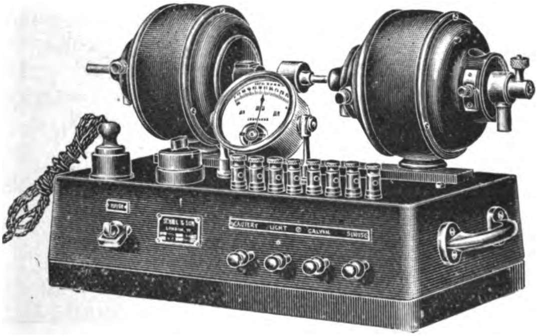

FIG. 10.—Pantostat.

If there is no main supply available the current from a battery of accumulators may be converted into a sinusoidal current by means of a motor transformer.

To understand the way in which sinusoidal currents are generated and the mechanism of motor generators and rotary converters, requires some knowledge of the working of motors and dynamos. This will be found on p. 371 *et seq.*

Measurement of Sinusoidal Current.—This current can be measured by means of a special form of amperemeter. It is described on p. 367.

Uses of Sinusoidal Current.—The sinusoidal is a valuable current for stimulating the tissues, and it is especially useful in the treatment of paralysis. It stimulates sensory nerves, and it is probable that organs are, thereby, stimulated reflexly. It can also relieve pain in certain cases of non-acute inflammation.

SLOW SINUSOIDAL ALTERNATING CURRENTS

The alternating currents on the mains have a periodicity not higher than 100 and not lower than 25. If there are fewer than 25 complete cycles per second (*i.e.*, 50 reversals per second), lamps that are illuminated by such a current will not give a steady light. Sinusoidal currents of a lower periodicity are sometimes used in medicine, and Dr. Reginald Morton has recommended the use of currents with a periodicity as low as 1.7—that is, in each second there are 1·7 cycles. The duration of each cycle would then be very nearly 0.6 second. Dr. Morton recommends the use of these currents for stimulating unstriped muscle.

Production of Slow Sinusoidal Alternating Current.—A slow sinusoidal current may be obtained from a dynamo when the armature is made to revolve slowly.

The field magneto of the dynamo requires a very strong current before a slow sinusoidal current, of sufficient strength, can be taken from the slowly revolving armature.

A slow-wave alternating current, though not sinusoidal in nature, can be obtained by using a device known as "Ewing's Rhythmic Reverser." If a galvanic current is passed through this apparatus, it will furnish a slow-wave current which may be used for purposes for which a slow sinusoidal current is required. A plan of this apparatus is shown in Fig. 11. It consists of a cylindrical glass vessel. It is filled with tap water. Inside the vessel is a thick disc of ebonite of slightly less diameter than that of the vessel. It is mounted so as to be free to rotate in the water of the vessel. Two metal armatures, C and D, are fixed to the inner sides of the wall of the glass vessel, at opposite ends of a diameter. Two other armatures, A and B, are fixed to the edge of the rotating disc. The disc is fitted to a vertical axle and on the latter are secured two small metal discs. One of these is connected by a wire to A, the other is similarly connected to B. Metal brushes make contact with these discs and lead off the slow-wave current where desired.

The metal armatures C and D are connected to a source of galvanic current. When the ebonite disc is revolved an alternating current can be obtained from the metal brushes, and the slowness of the waves depend on the rate of revolution of the disc.

The nature of the current and the way in which it is derived can be understood more easily if the following explanation is given. The galvanic current enters at C, passes along the water between the disc and the wall of the vessel, and leaves at D. There is consequently a fall of voltage along its path. By rotating the disc, the armatures can be moved along the same path through regions of different voltage. If there is a difference of voltage in the regions where the two armatures are immersed, a current will pass between them, along the circuit which includes them. Let us assume the voltage at C is 100. At D it is zero. In the position of the disc as shown in the figure, the armatures A and B are at the same voltage as C and D. The maximum current will then flow from A to B. If now, the disc is rotated through a right angle so that A is on the *north* side of the figure, half way between C and D, and B is on the *south* side, each will be in a region where the voltage is 50. No current can now pass from A to B. During the rotation of the disc through the first right angle the current from A to B sinks from maximum to zero. During the rotation through the next right angle, the voltage of A will fall from 50 to zero, while that

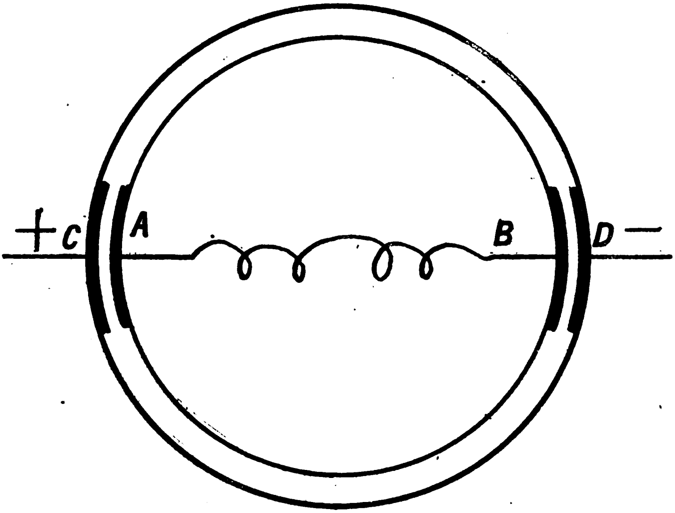

FIG. 11.—Plan of Ewing's Rhythmic Reverser.

of B will rise from 50 to 100. The current will, therefore, rise from zero to maximum but will flow in the opposite direction, viz., from B to A. During the rotation through the 3rd right angle, the current will sink again to zero, flowing from B to A. During the rotation through the last right angle, the current will again ascend to maximum, flowing from A to B.

We have, therefore, a complete phase. The current flows in opposite directions through each semi-phase. The duration of each phase depends on the speed of rotation of the discs.

The water rheostat (described on p. 53) will provide a slow-wave current. It produces the current on the same principle as Ewing's apparatus. If it is made so that the movable electrodes can be rotated around a complete circle, the complete phase is given. If the "Galvanoset" (Fig. 24, described on p. 54) is used the regulating handle can be moved to and fro between zero and the maximum required and the current provided will be a slow-wave current. The summit of the wave will be flattened.

Use of Slow Sinusoidal Current.—This current is sometimes used when stimulation of the muscle of the alimentary canal is desired.

FARADIC CURRENT

This current is obtained from the induction coil. Both the primary and the secondary windings of the coil yield a current. These are known as the *primary* and the *secondary* faradic currents, respectively. Both are interrupted currents, and the secondary faradic current is, in addition, an alternating current. A graphic record of the primary and secondary currents from an induction coil is shown in Fig. 13. The record is quite different from those shown in Figs. 3, 7 and 9. The rate of rise and fall of the current strength are unequal, both for primary and secondary currents, while in the latter, the duration of flow is not the same in each direction. The currents from different coils show variation in these points, although that from the primary is always unidirectional and that from the secondary is always alternating. The difference in the sensation accompanying the passage of the current from different coils is to be attributed largely to variation in the character of the current as indicated above.

Before explaining why differences in sensation is due to differences in the character of the current, the induction coil will be described.

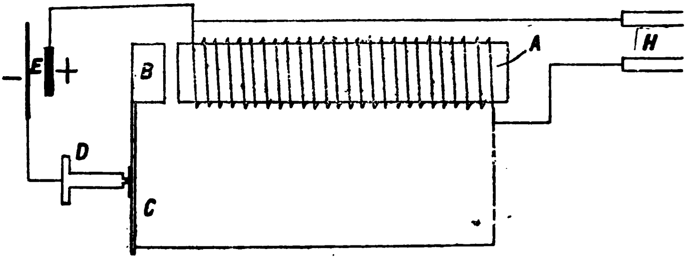

FIG. 12.

The induction coil is probably the best known electrical device in use by medical men and others. It is very inexpensive, especially in its simplest forms, and for stimulating living tissues it may be quite efficient. Many designs of medical induction coil are in existence, but they all work on the same principle. The essential parts are shown in Fig. 12.

A is an iron core—usually made up of a bundle of soft iron wires—around which is wound a comparatively a few turns of fairly coarse wire: this is the *primary* coil. In all cases the wire used for winding coils is covered with silk or cotten for purposes of insulation. Opposite one end of the core is an iron block, *B*, which is secured to the end of a metal spring, *C*. A screw, *D*, is mounted so that its point comes opposite about the middle of the metal spring. The end of the screw and that part of the spring with which it comes into contact are both faced with platinum. One end of the primary coil is connected to one pole of the battery, *E*—the other is connected to the spring, *C*. The other pole of the battery is connected to the screw, *D*.

Around the primary coil, but quite disconnected from it, is another coil of much finer wire and wound in very many more turns. This is the secondary coil. It is not shown in Fig. 12.

The secondary coil generally consists of a large number of turns of fine wire. It is not directly connected in any way with the primary, but is wound on a bobbin, the hole through the centre of which is large enough to slide over the completed primary coil. The secondary has from five to fifteen times the number of turns of the primary. The average proportion of primary turns to secondary turns is 1 : 10.

The course of the current can be easily traced from the battery to the primary coil, from this to the spring, *C*, thence through the platinum contacts to the screw *D*, and so back to the battery. The current passes round the primary coil, and the latter becomes, with the iron core, an electro-magnet. It thus attracts the iron block, *B*, and in drawing the latter towards itself pulls the spring, *C*, away from the point of the screw, *D*. Immediately this happens the circuit is broken and the flow of current from the battery ceases. The core thus loses its magnetism, and the iron block is no longer attracted. The spring, *C*, by its own elasticity flies back until it is stopped by the point of the screw, *D*. The circuit is thus again closed and the above-mentioned changes are repeated.

We may now consider the events that take place in the primary and secondary coils. Since the vibrating spring continually makes and breaks the primary circuit, the current flowing in this circuit (the primary current) is interrupted or intermittent. Further, at "make" and also at "break," an extra current is induced, not only in the primary circuit (the primary induced current), but also in the secondary circuit (the secondary induced current). These induced currents are of momentary duration. They may be taken in order:

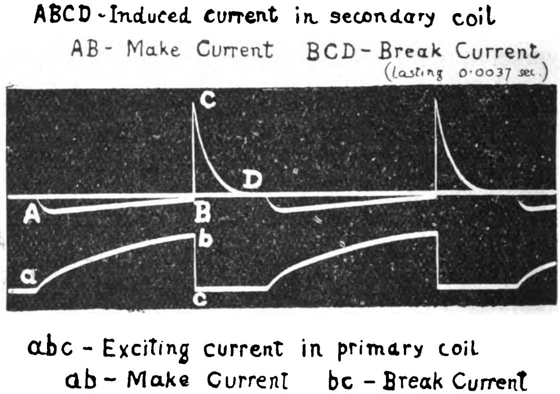

FIG. 13.—Graphic record of the primary and secondary currents of an induction coil. (Adapted, by permission, from Jones' *Medical Electricity*. 6th Edition. H. K. Lewis and Co., Ltd., London.)

1. *At "Make" of the Primary Circuit.*—The battery current flows around this circuit, but directly it starts it induces a new current in the same circuit. This "self-induced current" as it is called, is of momentary duration and (as described in Chapter XV. p. 369) flows in a direction opposite to that of the battery current. Its effect is to impede the latter and slow its rate of rise to its maximum. This is shown in Fig. 13, *a* to *b*. It indicates the slow rise of the current in the primary to the maximum. As a result

of this impeded rise, the current that it induces in the secondary coil is of correspondingly long duration and does not reach a high voltage (see Fig. 13, curve from *A* to *B*).

2. *At " Break " of the Primary Circuit.*—At the moment the primary circuit is interrupted the battery current ceases to flow, and at the same time an extra current is momentarily induced in the same circuit ; it flows in the *same* direction as the battery current, and therefore cannot impede the latter or slow its rate of fall to zero. The fall to zero is therefore abrupt (Fig. 13, *b* to *c*). This abrupt fall of the current in the primary induces in the secondary a current of brief duration, briefer than that of the current induced in the same coil at " make " and one at higher voltage (Fig. 13, *BCD*).

It is evident, then, that the faradic current is highly complex. Further than this, the graphic record of the output of induction coils varies greatly in coils of different design. The output depends on the length of the wire in the primary and secondary coils, the presence or absence of an iron core, the design of the vibrating spring, the method of regulating the output, etc. The output may also vary in the *same* coil from time to time, according to the adjustment of the hammer, etc. We may therefore speak, not of a faradic current, but of varieties of faradic current. Some designs of coil produce currents that cause painful and disagreeable sensations when applied to the body, while others produce no painful effect. One of the important uses of the faradic current is to stimulate motor nerves and muscles. The current which will produce strong muscular contraction without pain is the most suitable for this purpose. When the current induced in the secondary at " break " lasts not longer than $\frac{1}{1000}$ second it will effectively stimulate motor nerve and muscle, but sensory nerves which convey sensation of pain are not stimulated.

Motor nerves and muscles will respond to currents of very brief duration. Sensory nerves, however, require currents of longer duration. The current that is provided by an induction coil should last, during each period of flow, the briefest possible time, so that muscles and motor nerves may be stimulated, and not the sensory nerves. A coil giving a record like that shown in Fig. 13 would produce painful contractions of muscle, because the secondary current flows for periods that are long enough to stimulate the sensory nerves. Many other coils give currents that produce the same effect. A coil that is most suitable for stimulating motor nerve and muscle is one that produces the most vigorous contractions without disagreeable sensation. This requirement will be fulfilled if the induced current in the secondary at "break" is of the shortest possible duration, and that at "make" is of insufficient strength to cause skin sensation or muscular contraction. A coil giving a graphic record like that shown in Fig. 14 would give the most agreeable and painless contraction of the muscles. The records of the secondary in Figs. 13 and 14 are on the same scale. The record of the secondary current is given in Fig 14 (not of the primary), and it will

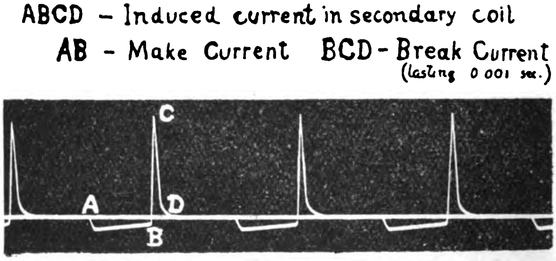

FIG. 14.—Graphic record of the secondary current from a well-designed coil. The record of the primary is not shown. (Adapted, by permission, from Jones' *Medical Electricity*. 6th Edition. H. K. Lewis and Co., Ltd., London.)

be seen that the duration of the current at "break" BCD is very brief ($\frac{1}{1000}$ second); that at "make" being of insufficient intensity to cause perceptible stimulation. An electrical stimulus or impulse is produced each time the current at "break" flows. The number of these impulses per second depends on the rate of vibration of the spring. In the record shown the number was nearly 100 per second. The coil shown in Fig. 15 was designed by Lewis Jones, and the oscillographic record shown in Fig. 14 was obtained from one of this design. It is a valuable coil for use in medical

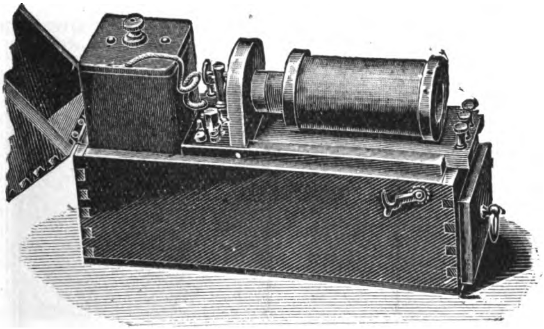

FIG. 15.—Sledge coil, of type originally designed by Lewis Jones.

practice, as the current will evoke strong muscular contractions without disagreeable sensation. It is enclosed in a case containing a dry cell and is portable. The primary circuit is completed and interrupted by a spring vibrating in a horizontal plane and actuated by the iron core within the primary coil. This core is not movable. The secondary coil can be made to slide as a sledge over the primary coil. The current that is applied to the patient is taken from the secondary coil and is regulated by sliding the secondary over the primary.

Another coil which can cause contraction of muscle without disagreeable sensation is the Smart-Bristow coil (Fig. 16). The make-and-break mechanism is a hammer which vibrates in a horizontal plane and is actuated by a separate electro-magnet. This is shown in Fig. 16 in the upper part of the case enclosing the primary and secondary coils. One of the special features of this coil is the method of regulating the strength of the current for the patient. This current is derived from the secondary coil and its strength is varied by sliding the iron core in or out of the primary coil. A handle is attached to the core for this purpose. It is seen in the figure, projecting from the interior of the case. Finer variations of the strength of the current can be effected by this method of

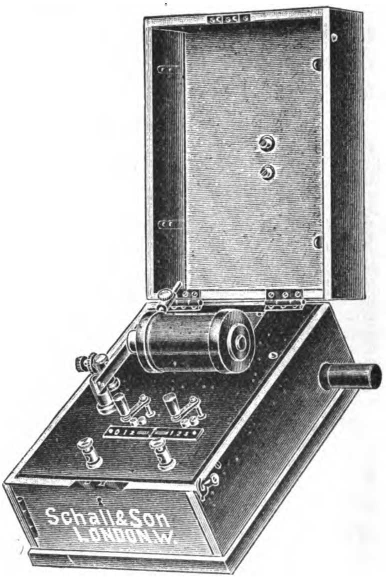

FIG. 16.—Smart-Bristow Coil.

regulation than by sliding the secondary over the primary coil. By means of a switch, either one, two, three or four divisions of the secondary winding can be included in the circuit according to the maximum strength of current required.

This coil is operated by dry cells placed in the interior of the case. When the iron core is completely withdrawn the induced current is weakest; and on the other hand, the further it is pushed back into the primary, the stronger the induced current becomes. This coil is used for producing rhythmic contraction of muscles. The operator slides the core in and out, thereby causing rhythmic increase and decrease of the strength of the current.

A very useful coil is that designed by Dr. Tripier and made by Gaiffe, of Paris. It has an interrupter which can be regulated to vibrate at any desired frequency, between 60 and 2,500 times per minute. The interrupter, shown diagrammatically in Fig. 17, is composed of a small iron rod supported at the middle so as to enable it to swing like a see-saw. The

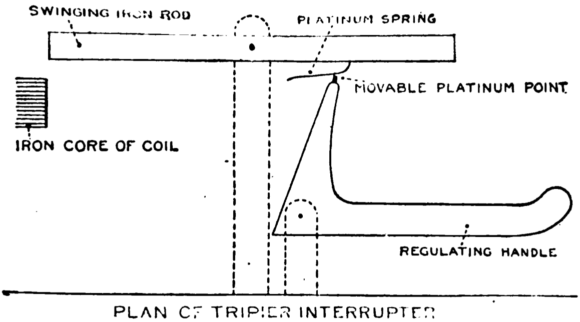

FIG. 17.—Plan of Interrupter fitted to Tripier and Physio Coils.

swing in one direction is caused by the iron core when magnetised by the current. This movement automatically interrupts the current, whereupon the rod swings back, by the action of gravity, to its former position. The frequency of the swing is regulated by moving a crank which brings a platinum point nearer to or further from the axle on which the plank swings. When the plank falls back, after attraction by the magnetic core of the coil, it comes into contact with the platinum point. The circuit is then completed, the plank swings towards the core and the circuit is interrupted. The nearer the point of contact to the axle the less frequent the interruption. The current passing to the patient is taken from the secondary coil, and its strength is regulated by sliding the latter over the primary. Two separate coils are provided.

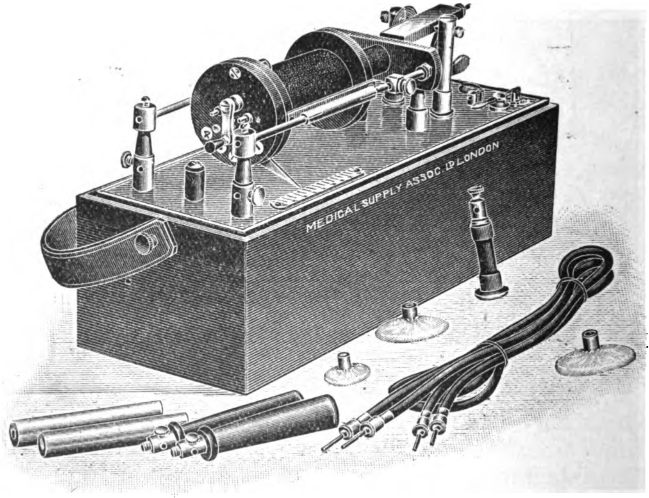
MEDICAL SUPPLY ASSOC. LD LONDON

FIG. 18.—Physio Coil.

One contains a relatively short length of wire of low resistance. In this coil is induced a low electromotive force but a strong current. The other secondary coil contains a great length of fine wire. In it is induced a high electromotive force but a weak current. The former current is used for procuring contraction of muscle, the latter for stimulation of the skin and its sensory nerve endings. A coil, designed by the Medical Supply Association, known as the "Physio" coil, is fitted with an interrupter like that just described. This coil is shown in Fig. 18. The secondary winding is divided into four parts. The current from one or more of these can be obtained, according to the strength desired for treatment, by moving a crank. Finer adjustment can be made by sliding the secondary coil over the primary. The secondary coil is mounted on two parallel metal rods or rails, along which it can slide over and off the primary coil, so that regular adjustment of the strength of the secondary current can be obtained, as well as rhythmic variation of its strength, when desired.

Properties and Uses of the Faradic Current.—This current is able to stimulate motor nerve and thereby cause contraction of voluntary muscle. It is used to produce artificial exercise of muscles which are paralysed or weakened. The induction coil chosen should be one which provides a current capable of causing strong contraction with the minimum amount of sensation. All the coils described above are satisfactory for this purpose. The treatment of paralysis is considered in Chapter IX.

The power of the faradic current to cause contraction of muscle can be utilised for the treatment of inflammation of fibrous tissue and muscles, accompanied by adhesions (fibrous and fibrinous) and exudation. The contraction of the muscle loosens the adhesions and mechanically aids the removal of exudation. A coil fitted with an adjustable interrupter must be used because single strong contractions must be produced, about one per second. Rapidly repeated interruptions cause tetanic contraction which it too painful.

The sensory nerve endings in the skin can be stimulated by the faradic current for the production of tonic effects, without contraction of muscle. The coils described above may be used for this purpose. A coil with a greater length of wire in the secondary, such a the Lewis Jones or Tripier coil, is probably more effective for this purpose, as the longer impulses stimulate sensory nerve endings more strongly than the very brief impulses furnished by a coil with short secondary winding. If the faradic current is applied to the body immersed in a bath, a coil with a longer secondary winding is necessary, as a higher voltage is required. The use of the faradic current for tonic treatment is described in Chapter VIII (p. 142) under "General Faradisation."

The faradic current is also used for procuring strong painful stimulation of sensory nerves. This treatment is used for hysteria, also for producing counter-irritation in neuralgia. A fine wire brush is used as an electrode. The current from a coil with a long secondary winding must be used, as a high voltage is required. This treatment is quite different from that just described, in which sensory nerve stimulation, *without pain,* is produced.

No essential difference in therapeutic properties has been proved between the primary and the secondary faradic currents. The secondary current is generally used, and as a lower electromotive force is induced in the primary coil, the current from the latter cannot be used for some of the purposes for which the faradic current is applied.

Measurement of Faradic Currents.—Instruments known as "faradimeters" have been devised, but are seldom used in clinical work. Dr. Sloan, of Glasgow, has designed a form of faradimeter.

Some Notes on Coil Construction.—We may now briefly consider the design of the medical coil in so far as it affects the current yielded. First of all, the mechanism for interrupting the primary current. The hammer should vibrate smoothly and evenly, in a horizontal plane. Hammers which move in a vertical plane vibrate irregularly, and the current induced in the secondary produces an uneven and unpleasant contraction of the muscles. The impulses at "break" are not all of equal duration and intensity. In the second place, there is the length of wire in the secondary. Some coils are made with a great length of fine wire in the secondary without an arrangement whereby only a portion of it can be used if desired. Currents from these coils cause a less pleasant sensation than those from coils with shorter secondary winding. The impulses at "break," and also those at "make," are long enough to stimulate sensory nerves.

Some coils are provided with an extra pair of terminals so that the primary induced current can be applied to the patient. In Fig. 12, *H* represents the handles that lead this current to the patient. The current that the patient receives is that induced at "break," that induced at "make" being too small to be perceptible. The primary induced current is more agreeable to the sensation than the secondary when the coil has not been designed with the object of making the latter painless. The primary induced current is regulated by sliding a brass tube over the iron core.

Other coils have an arrangement in the form of a bent wire with a sliding ball that can be fixed to the hammer for the purpose of regulating the rate of vibration of the latter.

THE GALVANO-FARADIC CURRENT

This current is a combination of the faradic and galvanic currents. Each is separately generated and passed simultaneuously through the body. The galvanic current should flow in the same direction as the faradic at break. A special key, known as the "De Watteville key," is used when the combined current is applied. By means of this device, the galvanic and faradic currents can be applied separately or together.

The combined current does not possess, so far as is known, properties other than those peculiar to the component currents, but muscles may be made to contract with a weaker faradic current when the galvanic current is flowing simultaneously along the same path. Occasionally it is found that a muscle can be made to contract by the faradic current, only when the galvanic current is flowing at the same time.

The combined current is preferred by some workers for the treatment of paralysis, especially when the reactions of the muscles are changing from RD. to normal. (For meaning of RD. see p. 188).

THE THREE-PHASE CURRENT

This current is a sinusoidal alternating current applied by means of three electrodes. The direcion of its flow through the body between the electrodes can be more easily followed by reference to Ewing's Rverser (Fig. 11). If, instead of two armatures (A and B), three are fitted to the ebonite disc, and placed equidistantly around its circumference, each being connected to a separate metal disc on the axle, a three-phase current will be delivered to the three terminals by way of the metal brushes which make contact with the discs. As the ebonite disc revolves, the armatures pass through regions of increasing or diminishing voltage, and a current will flow through the body from the armature at high voltage to the armatures which are at lower voltage. Suppose that these armatures are numbered 1, 2, and 3. When 1 is in the region of the highest voltage (opposite C) the current will flow from 1 to 2, from 1 to 3, and from 3 to 2. When the disc has moved through a third of a revolution, and 3 is in the region of the highest voltage, the current will flow from 3 to 1, from 2 to 1, and from 3 to 2. When the disc has moved through the next third of a revolution, the current will flow from 2 to 3, from 1 to 3, and 2 to 1. When the disc has moved through the final third it will be in its first position.

A three-phase current can be derived from a Ewing's reverser, modified in the way described. It can be obtained from a dynamo with a specially wound armature.

By means of the three-phase current-generator, a sinusoidal current can be directed along three paths, and three regions treated simultaneously. The duration of each wave is determined by the speed of revolution of the armature.

The three-phase current has been recommended for stimulation of the muscle of the alimentary canal.

The high-frequency and diathermy currents and the static wave and static induced currents will be described later, in the chapters dealing with these forms of electrical application.

CHAPTER III

SOURCES OF ELECTRICAL SUPPLY

WHEN it has been decided to make use of electricity for the treatment of disease, the first practical question which arises is that of supply. There are different sources of supply and the selection will depend on what is available and most convenient. In almost all the applications of electricity for medical purposes, a current of one or another kind is used, and the current which constitutes the source of supply may require modification according as it is used either for direct application to the body or for the generation of other kinds of current, or for other purposes. There are the following sources of supply :

1. The Street Main.
2. Cells and Accumulators.
3. Dynamo and Driving Plant (private installation).

Each of these has its advantages and limitations. These will be set forth in the present chapter, together with the methods of modifying them so as to render them suitable for different purposes. For the generation of static electricity an influence machine is required, with an electric motor or gas or oil engine to drive it.

CURRENT FROM THE MAIN.—The town supply that is distributed along the street main and taken into many of the houses is the most convenient and econominal source. The current is, in some towns and districts, a *direct* current (DC)—*i.e.*, its direction is unvarying. In others it is an *alternating* current (AC)—that is, its direction is periodically reversing. The voltage at which it is supplied is not always the same in different towns; in some it may be 100, in others 200 or 250. And in the case of the alternating current the frequency of the alternation differs in different towns. It is therefore necessary to find out, with regard to the town current, whether it is a direct or an alternating current, the voltage at which it is supplied, and the frequency of the alternation when the town supply is an alternating current. These particulars are published each year in the January number of *The Electrician*.

It must be borne in mind that the currents which are taken into private houses from the street mains are intended primarily for the purpose of lighting lamps; their voltage and amperage are suited for this purpose. If they are to be used for medical purposes their voltage and amperage have to be altered according as they are used for direct application to the body, or heating cautery burners, or illuminating surgical lamps, or for the production of other currents. The nature of the alteration for each purpose and the ways in which it may be brought about will now be described.

THE USE OF THE DIRECT CURRENT FROM THE MAIN

1. *For Direct Application to the Body, as for Ionisation, etc.*—For this purpose, the voltage must be reduced. The simplest and least expensive way of doing this is to insert a sufficiently high resistance. This resistance could be inserted *in series* with the patient, in which case the patient and the resistance would both be in the same circuit, and the current would traverse each in turn (Fig. 19, B). Such an

arrangement is unsatisfactory, and the usual plan is to arrange the resistance *in shunt*. In this case the patient and the resistance are in separate circuits, and the current traverses each simultaneously (Fig. 19, A), the amount passing through each depending on their relative resistances. The resistance in the patient's circuit can be varied by including in the same circuit a varying length of the shunt resistance. This can be effected by connecting one of the wires leading to the patient to some point on the shunt resistance a varying distance from the end of the latter. With such an arrangement, part of the shunt resistance is in series with the patient.

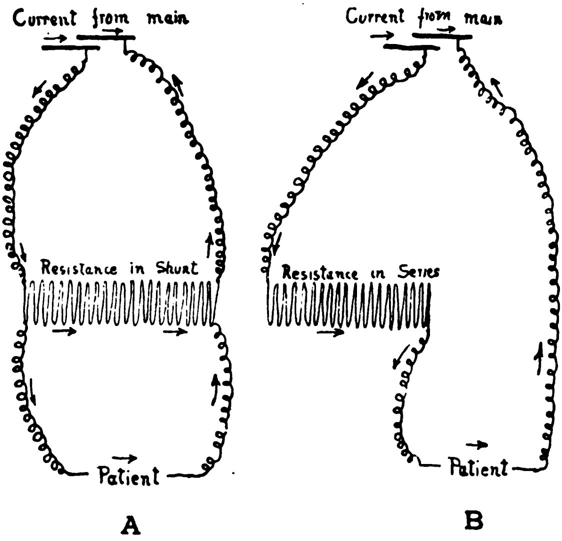

FIG. 19.—Current derived from main with resistance *in shunt* (A), *in series* (B).

Fig. 20 is a diagram showing the necessary arrangement. The fine wire coil, from A to B, and the lamp at B constitute the shunt resistance. If we trace out the connections we see that the current comes in from the main at the positive terminal to the switch. When the switch is turned on, the current flows through the fine resistance wire from A to B, then through a lamp and safety fuse to the negative terminal of the main.

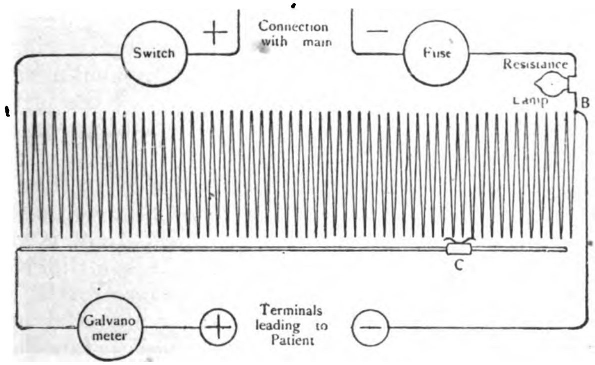

FIG. 20.—Plan of Shunt Resistance.

It also flows, when the patient is connected, along part of the length of the fine wire to the slider, C (this can be moved to the right or to the left), then through the galvanometer and through the patient back to the other circuit at B. The strength of current that passes along these two circuits will depend upon their relative resistances. The resistance of the circuit containing the fine wire and the lamp is constant, that of the other circuit containing the patient will depend upon the length of resistance wire between A and the slider, C.

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On the + side of the connection with the main (Fig. 20), the voltage is at the maximum supplied on the main; on the — side of the connection it has fallen to zero. The fall takes place gradually and evenly along the resistance from A to B. A further fall takes place in the lamp at B, and zero is reached on the — side of the fuse. From A to B the fall is even—there is a "slope of potential," as it is called.

If we take a sensitive voltmeter and connect one terminal to B, and having attached a piece of wire to the other terminal of the voltmeter, draw the free end of this wire across the turns of the resistance from B to A, we shall find that we can get any voltage we desire from zero up to the highest given by the instrument—this will be from 50 to 80, depending on the resistance of the lamp at B.

Now it will be seen on reference to Fig. 19 that the patient is connected in the same way as the voltmeter. One of the terminals that lead to the patient is connected to B, the other is connected with the slider, C, which can be moved along the resistance coil, AB, and in contact with it. This slider, C, is mounted on a metal rod that is placed parallel to the resistance coil and at such a distance from it that its springs are always in contact with it. The voltage of the current that passes to the patient can therefore be varied between zero and maximum by sliding C along the resistance coil from B to A. When the slider is at B, the terminals that lead to the patient will be in connection with the same region of the resistance coil, and there will be no difference of potential between the terminals, and no current will pass to the patient. On moving the slider farther and farther away from B towards A, the voltage between the terminals will rise higher and higher, and more and more current will pass to the patient. The strength of the current is indicated by the milliamperemeter placed in the same circuit with the patient.

Fig. 21 is an illustration of the actual apparatus, the plan of which has been described. The various parts are mounted on a board that can be fixed permanently to the wall. At the top are mounted the lamp, switch and safety fuse. Underneath is the resistance coil. In front of this is the slider which can be moved from side to side over its surface. The scale below the resistance coil serves to indicate the position to which the slider has been moved on any occasion. At the bottom of the board are two terminals to which will be fixed the cables that lead the current to the

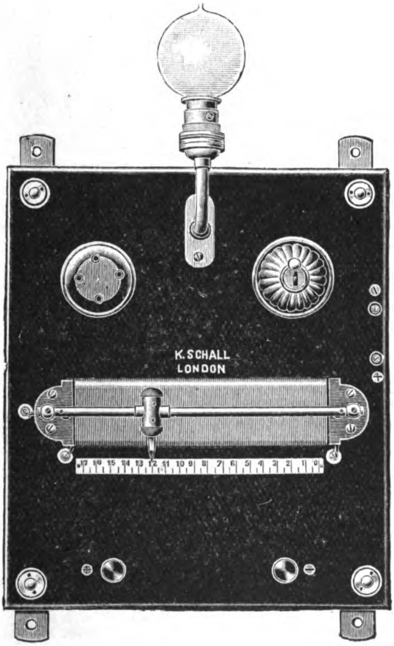

FIG. 21.—Shunt Resistance.

patient. A milliamperemeter is not attached to this board.

Fig. 22 shows a similar apparatus, contained in a box, so that it is portable.

The current which is given by the apparatus described may be varied, by adjusting the position of the slider, between a fraction of a milliampere and 300 milliamperes, so that it is suitable for all purposes for which a constant current has to be applied direct to the body—viz., ionisation, electrolysis, etc. Its voltage can be varied between zero and a maximum of about 80.

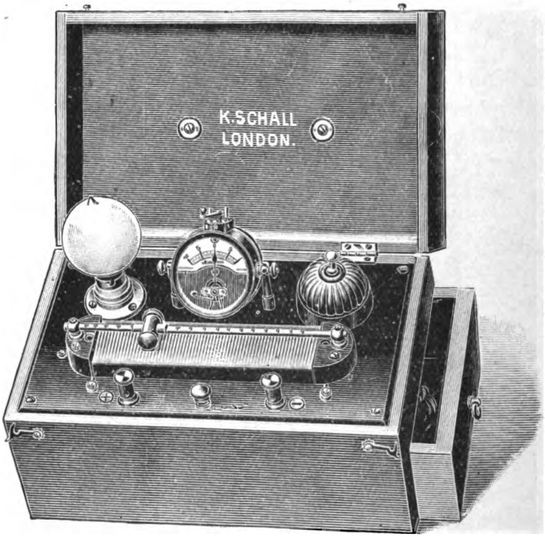

FIG. 22.—Portable Shunt Resistance.

The current that is taken by the apparatus from the main is not large, and it may be taken with safety from a lamp-holder or wall plug.

A more elaborate switch-board is shown in Fig. 23 A voltmeter and a milliamperemeter are fitted so that

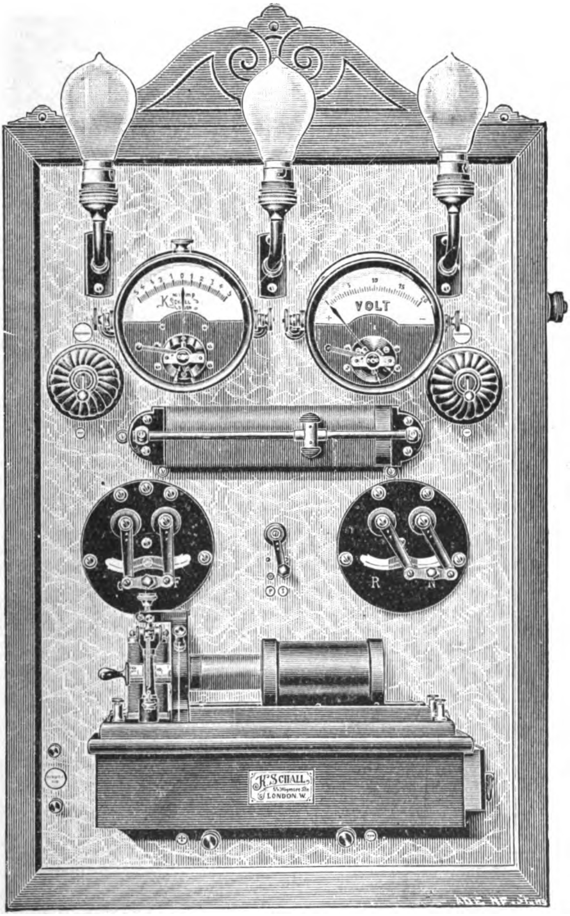

FIG. 23.—Galvano-Faradic Outfit.

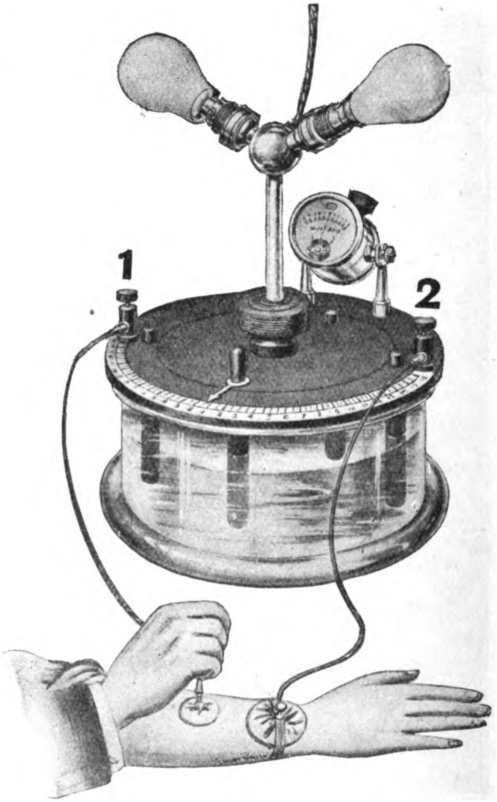

FIG. 24.—The Galvanoset.

the voltage and amperage of the direct current that is supplied to the patient can be measured. There is also a reverser, so that the direction of the current may be altered as desired. An induction coil is also fitted. It is worked by the current from the main, suitably reduced by the lamp shown on the top left-hand corner of the board. Either the faradic or the direct current, or both together, can be led to the two binding screws shown at the bottom of the board, and thence to the patient, according to the adjustment of the key shown on the left side of the board just above the induction coil.

The voltmeter is not essential, but it is very convenient to have. It shows the difference of potential between the electrodes applied to the patient, and by its use, rough approximations of the resistance between the electrodes can be obtained by taking the reading in volts and milliamperes and working it out by Ohm's law.

Water rheostat.—A new device, in which water is used as a resistance instead of a wire coil, has recently been introduced. It possesses special advantages. An absolutely steady and even increase or decrease in the strength of the current can be obtained. With the apparatus already described the variation in the current strength is slightly uneven as the slider moves over the wire coils. Further, when a wire resistance is used one of the coils may break, and when this happens, a strong current from the main may pass through the body of the patient. This cannot occur when water is used as the resistance. The following is the description of a simple form of water resistance.

A cylindrical glass or china vessel is filled with tap water; 8 inches in diameter and 4 inches in depth is a suitable size. Two carbon rods, 6 inches long, are placed vertically in the water at opposite ends (say one at north and the other at south). The current from the main is made to traverse the water from one carbon to the other. The current to the patient is led off from the water by means of two other carbons, which also dip vertically into the water at the circumference, one at west, the other at east. In this position no current flows to the patient. But if the two latter carbons are moved around the circumference, one from west to south, the other from east to north, a current will pass to the patient, its strength gradually increasing the further the carbons are moved around the circumference. If the carbons are moved in the opposite direction—viz., one from west to north, the other from east to south—the direction of the current to the patient will now be reversed. The advantages of this form of rheostat are the perfectly even gradation of strength of the current, the ease with which it can be reversed, the safety to the patient, and its simplicity. The movement of the carbons is easily effected by means of their attachment to a bar that rotates horizonally above the glass bowl, with its centre corresponding to the vertical axis of the latter.

The apparatus known as the *Galvanoset* is constructed on the principle described above. It is shown in Fig. 24. The current from the main is passed through the two resistance lamps supported on the pillar before it flows through the water.* A pointer moving over a graduated scale indicates the position of the movable carbons. When it is at zero, no current can pass to the patient. When the regulating handle is moved from zero the current to the patient gradually increases without the slightest irregularity. If the handle is moved in the opposite direction the current alters its direction through the patient.

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* The carbon connected to the positive cable of the main circuit gradually disintegrates. In the latest models of the *Galvanoset* it is replaced by a strip of platinum foil enclosed in a perforated celluloid tube.

2. *The Use of the Direct Current from the Main for obtaining a Sinusoidal Alternating Current.*—When the latter current is desired it may be obtained from the direct current from the main by means of a *motor generator*. This is described more fully on p. 63, but here it may be said to consist of an electric motor with a specially wound armature. When it is connected to a source of direct current, a sinusoidal alternating current can be drawn off from the revolving armature. Manufacturers of electro-medical apparatus now make motor generators that provide a sinusoidal alternating current suitable for direct application to the body. They are fitted to the so-called "Universal Apparatus" sold under the trade names of "Pantostat," "Multostat," "Polystat," "Plurostat," according to the maker. Such apparatus furnishes, in addition to the sinusoidal alternating current, currents for heating cauteries and lighting surgical lamps, and also a direct current for ionisation and electrolysis. The motor generators fitted to the "Universal Apparatus" take only a small current, and can be safely connected to a lamp-holder or wall plug. A "Universal Apparatus" forms a useful part of the equipment for a medical practitioner of Electro-therapeutics. A "Pantostat" is shown in Fig. 10, and described on p. 63.

3. *The Use of the Direct Current from the Main for heating Cautery Instruments.*—The direct current from the main may also be used for heating the cautery, but here again it requires modification. A cautery has a very low resistance, a small fraction of an ohm, and an electro-motive force of two volts would cause a current of sufficient strength to heat the platinum wire to redness. A current of 12 to 18 amperes is required. The current obtained by means of the shunt resistances previously described is far too weak as it is not more than 300 milliamperes (0.3 ampere). Neither this current nor the unaltered

main current are suitable for cautery instruments. Although it is possible to obtain a cautery current from the main, a better and more economical plan is to use a motor generator. Those fitted to the different forms of "Universal Apparatus" provide currents for heating cautery instruments.

4. *For Illumination of Surgical Lamps.*—For the illumination of surgical lamps like those fitted to the ophthalmoscope, cystoscope, etc., we require a current of lower amperage than for cauteries, but higher voltage. If the lamp filament is long and thin it will have a higher resistance, and the current must be at higher voltage. Short thick filaments have a lower resistance and require a lower voltage, but a higher amperage, if it is to be raised to incandescence.

For quite small lamps the apparatus first described, for providing currents suitable for direct application to the body, may be used. For larger lamps accumulators can be used. The "Universal Apparatus" provides a current suitable for lighting surgical lamps.

5. *For Operating Induction Coils.*—The direct current from the main is also suitable for working the large induction coils used for the production of high-frequency currents and X-rays. These coils usually take more current than that carried by the cables passing to a lamp-holder, so that it is generally necessary to fit heavier cables.

6. *For Operating Diathermy Machines.*—For the diathermy machine the *direct* current is unsuitable.* It must be converted into an alternating current. This is done by a motor generator, and one must be used that can provide an alternating current of at least 10 amperes at 100 volts. The current that is taken by this generator is heavy and cannot be carried on the house cables. Specially heavy cables must be

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* A small portable diathermy machine, made by Schall, is operated by the *direct* current. (See p. 241.)

taken into the house from the street main, sufficient to carry 20 amperes. The sinusoidal alternating current furnished by the small motor generators fitted to the "Universal Apparatus" is not sufficiently strong to operate diathermy machines.

THE USE OF THE ALTERNATING CURRENT FROM THE MAIN.—The alternating current is less convenient as a source of supply than the direct current. If it is to be used as a source of direct (constant) current, a motor generator will be required. It is, however, very suitable for heating cautery instruments and lighting surgical lamps, and it is the current required to operate diathermy machines. It is specially useful from the fact that it can be made, by means of a simple device, known as a "static transformer," to induce other currents of desired voltage and amperage. These new currents can be induced in separate circuits quite disconnected from the main, so that when the body is included in these circuits for the application of sinusoidal alternating current, there is no risk of obtaining shocks by touching objects connected with the earth. How these risks arise will be explained later (page 64).

As with the direct current from the main, the voltage and amperage of the alternating current from the main must be altered according to the purpose for which it is required.

1. *For Direct Application to the Body.*—When it is desired to make use of the therapeutic properties of the sinusoidal alternating current, the voltage and amperage of the main current must be lowered. A static transformer should, however, be interposed between the source of the current and the shunt resistance.

A static transformer consists of a core of soft iron, around which are wound two separate coils of insulated wire. One of these coils is called the primary coil, the other the secondary. These coils form quite distinct and separate circuits. The alternating current from the main passes through the primary coil, and as it oscillates to and fro, induces another alternating current in the secondary. It is not possible, with proper insulation, for the main current in the primary coil to get into the secondary coil. The voltage and amperage of the current induced in the secondary depends upon the number of turns of wire in this coil, as compared with the number of turns in the primary. If there are fewer turns in the secondary, the induced current will be of lower voltage and higher amperage (suitable for cautery and lamps); if there are more turns in the secondary than in the primary, the induced current will be of higher voltage and lower amperage. This transformer is called a *static* transformer, as it has no moving parts, unlike the *motor* transformer.

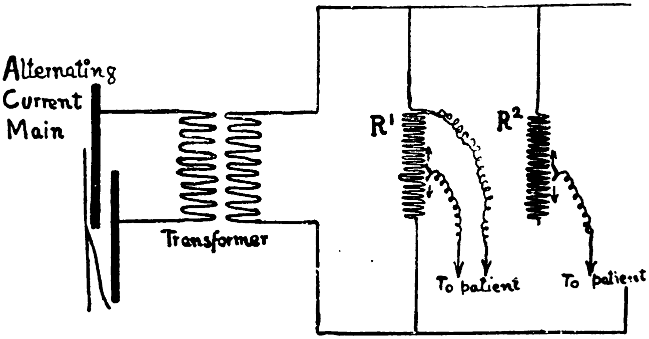

FIG. 25.—Scheme for derivation of current from alternating current main by way of a transformer, and regulation of current by means of a resistance either in shunt (R^1) or in series (R^2).

Fig. 25 shows a plan of the connections of the transformer with the main on one side and the resistance and patient on the other. The secondary coil of the transformer should have the same number of turns as the primary when the sinusoidal alternating current is to be applied to the body. The voltage and amperage of the induced current can then be lowered by means of a shunt resistance. If a number of patients are to be treated at the same time, the voltage of the induced current will have to be raised above that of the current from the main if that of the latter is not higher than 100.

A sinusoidal current suitable for use in electric baths should always be obtained from a static transformer. The secondary of the transformer is wound so that the voltage of the induced current is high enough to overcome the resistance of the baths in the circuit. It has to be raised above 100 if there is more than one bath in the circuit; the transformer is then known as a "step-up" transformer. Regulation of this induced current can be effected by means of a *shunt* resistance of the same kind as that used for lowering the voltage and amperage of the direct current from the main (described in the early part of this chapter) or by a *series* resistance. A shunt resistance is more suitable. Another way of regulating the current is to lead it through a coil of wire, like the primary of an induction coil, and let it induce another current in a separate coil that can slide over the primary as a sledge (like the secondary of an induction coil). This last current is taken to the patient and its strength can readly be regulated by sliding the secondary over the primary.

2. *For Cautery and Light.*—A static transformer suitable for deriving a current for cautery and light is shown in Fig. 26. The transformer is fixed to the upper part of the board. The alternating current, taken from a lamp-holder or wall plug (the primary coil of the transformer takes a current of about 2 amperes), passes to the primary coil of the transformer. On the secondary coil is wound a smaller

number of turns of wire so that a current of lower voltage and higher amperage (also alternating) is induced in it. This current, which is suitable for heating cauteries and has an amperage of about 18, is led to the two terminals on the bottom left-hand corner of the board.

There is another secondary coil also wound over the primary, and the number of turns is arranged so that a current of about 2 amperes at 15 volts is induced

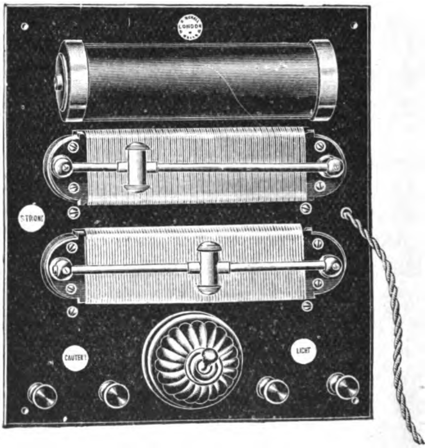

FIG. 26.—Transformer for Light and Cautery.

in it. The current is suitable for lighting lamps. It is led to the terminals at the bottom right-hand corner of the board. The amperage of the cautery current and the light current may be further regulated according to the requirements of the instrument or lamp used. The regulation of each current is effected by a "rheostat" (a variable resistance). Each rheostat is made of a coil of resistance wire, and a variable length of it can be included in the circuit (in series) by altering the position of the slider. The upper rheostat is for the cautery current, the lower for lamp current. For both of these currents the voltage has been lowered. The transformer is therefore known as a "step-down" transformer.

3. *The Use of the Alternating Current as a Source of Direct Current.*—For the purpose of electrolysis, ionisation, etc., for which an alternating current cannot be used, some method must be adopted for converting the alternating into a constant (direct) current. This can be done by means of a motor generator adapted so as to work when supplied by an alternating current. "Universal" apparatus can be made so as to take an alternating current, and it will then provide a direct (constant) current suitable for direct application to the body, as well as a sinusoidal alternating current for the same purpose, and currents for light and cautery. (See description of "Universal" apparatus on page 63).

4. *For Operating Induction Coils.*—For this purpose a constant (direct) current is required. The large induction coils used for X-ray work or high-frequency apparatus require a stronger current than that provided by the "Universal" apparatus. It is therefore necessary to use a more powerful motor generator. The alternating current from the main can, however, be used to work high-frequency apparatus; the induction coil is replaced by a step-up transformer with a large number of turns in the secondary, so as to raise the voltage of the induced current to the degree required.

5. *For Diathermy.*—For operating the diathermy machine an alternating current is required, and the voltage of this current should be 100 and the amperage not less than 10. The cables that are fitted to a house for ordinary lighting purposes would not take a current of this strength. It is therefore necessary to introduce cables into the house that can take 20 amperes.

The Use of Rectifiers with the Alternating Current.—There is a device known as the "Aluminium Rectifier" which will allow the passage of a current in one direction, but not in the other. If, therefore, it is included in the circuit of an alternating current, only those portions that pass in one direction will be allowed through, and the current will now flow only in one direction. It will, however, not be constant, but intermittent.

The rectified alternating current can be used for many purposes for which continuous currents are necessary. For charging accumulators some authorities consider it superior to constant current. It will drive continuous current motors quite satisfactorily and can be adapted to operate large spark coils so as to give excellent results.

The aluminium rectifier depends for its action on the peculiar property of this metal in that it offers a very high resistance to the passage of a current when it is made the anode of an electrolytic cell, but it offers no particular resistance when it becomes the kathode.

A rectifier may be made of a jar containing a saturated solution of ammonium phosphate in which are partially immersed, without touching, a rod of aluminium and another of iron. A current is able to pass through the solution from iron to aluminium, but not from the aluminium to the iron. It is impossible for this rectifier to get out of order under ordinary circumstances, and it is quite independent of any temporary interruption of the main current. They are made of various sizes, the larger of which can be used for large spark coils and for direct current motors, as well as for charging accumulators. What is known as the Nodon Valve is a rectifier constructed on this principle. These rectifiers have to be made very bulky when currents of any magnitude are passed through them, otherwise they become very hot.

Motor Generators. Universal Apparatus.—Manufacturers of electro-medical apparatus now make forms of so-called " universal " apparatus. Such apparatus can be connected to the main, either the AC or the DC, by way of a lamp-holder or wall plug, and then can be made to furnish four or five different currents, all of which are on circuits quite separate from the main. One of these currents is a direct (constant) current, another is a sinusoidal current. Both of these have a voltage and amperage suitable for application to the body. A third current is suitable for surgical lamps, and a fourth for heating cautery instruments. In some forms of universal apparatus an induction coil is fitted, so that a faradic current is available as well. Different forms of " universal " apparatus are sold under the names " Pantostat," " Multostat," " Polystat," " Plurostat," etc., according to the maker. The essential part of these machines is a motor generator. A motor generator is a combination of a motor and a dynamo. The motor operates the dynamo, and the latter generates a new current. The motor is constructed to suit the current which is available on the main.

A Pantostat is shown in Fig. 10. On the right-hand side of the base is the motor, on the left side is a dynamo. The axles of each are connected by an insulating rubber ring. The motor is connected to the main, and as its armature revolves its movement is communicated to the armature of the dynamo by means of the connected axles. Thy dynamo generates a constant current at a voltage suitable for direct application to the body. This current is on a circuit quite separate and distinct from the main, and so may be safely applied to the body either by way of pad electrodes or water in a bath.

As the armature of the motor revolves, a sinusoidal alternating current can be collected from its windings. This current is taken to the primary coil of a static transformer. There are three separate secondary coils wound round the core of this transformer. In each of these is induced a sinusoidal alternating current, but the number of turns is arranged so that one of the induced currents is suitable for cauteries, another for lamps, and the third for direct application to the body. Each of these currents is on a circuit separate from that of the motor in which the main current flows. Five sliding rods can be drawn out from the base of the Pantostat. One regulates the strength of the current passing to the motor. The others regulate the strength of the currents for cautery and light, and the sinusoidal and constant currents that are applied to the body. The regulation is effected by varying a series resistance. By means of a switch either the sinusoidal or the constant current, or both together, can be led to the patient. The milliamperemeter measures the strength of the constant current.

In some designs of "universal" apparatus, and in the older forms of the Pantostat, the motor and dynamo are combined in one machine.

Dangers attending the Use of Currents derived from the Mains.—At this stage it will be well to point out the risks that are run when current derived from the main is used for medical treatment, and show how they arise and how they may be avoided.

In all cases where patients are being treated by means of electricity derived from the street mains, there are certain precautions which must be observed to prevent accident. On account of the voltage and amperage of the main current, it is always possible to give unpleasant, even dangerous, shocks. Even if such an accident should not be attended by serious results, it is very disconcerting to all concerned, and patients sometimes strongly resent even slight shocks if they have not been warned beforehand. Carelessness in this respect leads to loss of confidence on the part of the patient, and possibly even the loss of the patient.

To understand why it is possible to obtain shocks when the current from the main is used, even with a shunt resistance, attention must be paid to the way in which the current generated in the power station is distributed along the mains. A system of distribution known as the three-wire system comes from the generating station in the form of a three-wire cable. One of these is the positive, another is the negative, and the third is neutral and acts as a common return to the others. All three are insulated from each other.

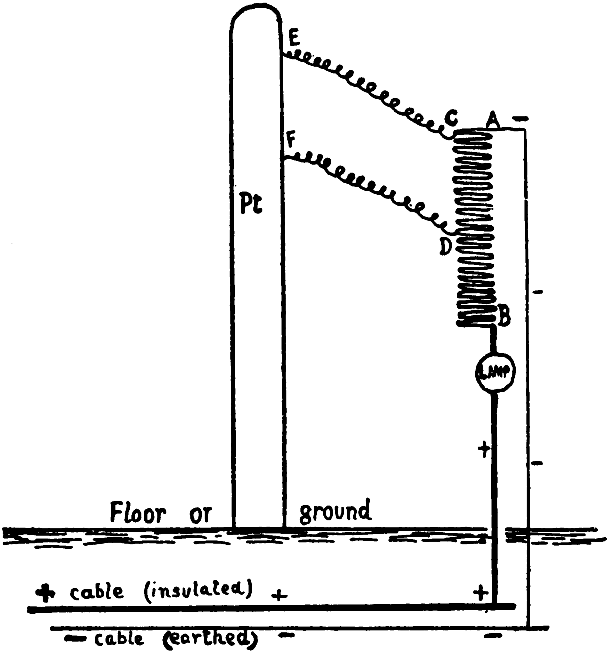

FIG. 27.

The neutral is positive to the negative wire, and negative to the positive wire, and, by a rule of the Board of Trade, must be connected to earth. Consumers are supplied from the neutral and one or other of the other two. The earth is a good conductor of electricity. Anything that is connected to earth by a conductor ("earthed" is the customary expression), such as metal water-pipes, radiators, electric-light fittings, streams of water coming from pipes (metal or rubber), stone floors, wooden floors when damp, is therefore connected to one of the main cables (the neutral one). Now if the patient is in connection with the other cable he has only to touch any one of the objects named to get the current from the main through him. If the patient has damp boots resting on a wet floor or on water-pipes or other earthed objects, he will be in connection with the neutral cable and will receive a shock if he touches the other cable. The operator may be touching an earthed object: if then he touches the patient, a shock will pass through both.

It is therefore necessary that a patient under treatment should be so disposed that no conductor connected to earth is within his reach. The floor should be quite dry, and, if it is made of wood or stone, should be covered with some non-conducting material, such as linoleum. It must not be forgotten that water containing substances in solution (and therefore a conductor) may drip out from the damp pads and moisten the floor, and make its way between adjacent pieces of the non-conducting material covering the floor, thereby establishing an earthed contact for the foot to touch.

In the diagram (Fig. 27) is shown a patient (Pt) receiving treatment by a direct current taken from the main, with a shunt resistance interposed, as described in the early part of this chapter. Two of the main cables are seen under the ground, and one of these (the neutral) is connected to earth. Suppose that the first cable is positive, the neutral cable becomes negative to it. The + cable is insulated from everything. A shunt resistance, BA, and lamp are shown and are supposed to be in a room. When the main

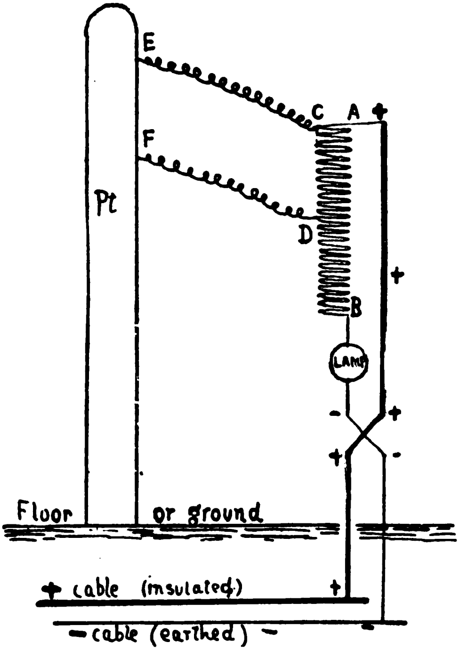

FIG. 28.

current is switched on, it passes from the insulated + cable up into the room, through the lamp, then through the shunt resistance, BA, then back to the earthed negative cable. CDFE is the circuit that includes the patient (Pt). Part of the current passes through this circuit. Let us suppose that the patient is earthed (touching a radiator or water-pipe or electric switch, or standing on a non-insulating stone floor, or a damped wooden floor; or he may be touched by a friend who is earthed). The main current, besides taking the path described, can also travel through the lamp, along the shunt resistance as far as D, then to the patient at F, then through the patient to earth and the negative cable. But little or no shock will be felt because the main current will be greatly weakend by its passage through the resistance offered by the lamp. the shunt resistance from B to D and the patient; and much of it will pass through the remainder of the shunt resistance from D to C and back to the earthed cable. But when D is placed closer to B, a shock will probably be felt, but will not be very severe because the main current still has to pass through the lamp resistance. Now suppose that the current from the main is taken to the shunt resistance in the opposite direction. This may readily be done by altering the position of the two-point plug that leads the current to the shunt resistance. Reference to the diagram shown in Fig. 28 shows that a short circuit will be formed through the patient if he is earthed and he will then receive the full pressure of the current from the main. The current will pass from the positive cable to A, along CE to the patient, and through his body to earth by way of the earthed conductor with which he is in contact. The patient would then receive a very severe shock.

Such an accident could be prevented by making the plugs so that they can be fixed in only the correct position, providing, however, that the main current is always in same direction. It is safer to have two resistance lamps instead of one, and place one on each side. The current will then be compelled to pass through a lamp resistance, whatever its direction along the shunt resistance. An additional precaution, which should always be taken, is to make the current pass through two additional lamps that are permanently in position on a switch-board on the wall before entering the other lamps and shunt resistance. It is always advisable to use two lamps, because if the filament fuses the metal may fall across and make a short circuit at the base of the lamp, and so cut out most of its resistance: if there is only one lamp, the sudden increase in the strength of the current passing through the shunt resistance and the patient, would cause a shock. There is another possibility of accident, as the resistance wire may break, and if the breakage occurs between A and D (Fig. 27) the current must all traverse the patient to get back to the negative cable. The shock that the patient receives is not likely to be severe, unless there is a greater length of wire included between A and D. This risk may be almost completely avoided by using two shunt resistances connected in parallel, so that the current traverses both simultaneously.

If the precautions mentioned above are taken, the direct current from the main may be used for application to the body, either by means of pad electrodes or the Schnee bath. Accidental shocks, though disagreeable, are never fatal, because the current is applied only to relatively small portions of the body. In the case of the full-length bath the case is different. Here the patient is quite devoid of any protection which a dry skin or clothing might otherwise afford him, and is also quite unable to help himself quickly when immersed in the water of the bath. If it is desired to apply the direct current from the main to a full-length bath, the precautions already mentioned have to be taken, and, in addition, the bath itself must be completely insulated from earth.

To thoroughly insulate the bath is practically impossible in the case of those already fixed, but it can be done if the bath is installed with that end in view. The electric bath at the London Hospital is completely insulated and is satisfactory. The bath itself is of porcelain. Large rubber pads, about one inch thick, are placed between the bath and the cement pedestals upon which it rests. Part of the waste-pipe consists of a length of rubber hose—leakage of current may occur here along the thin layer of water left in the pipe, but its resistance is high enough to render it negligible. The water-pipes are kept clear of the bath and discharge from a point high up out of reach of the patient.

The late Dr. Lewis Jones considered that "no method which depends for its safety upon the maintenance of insulation from earth of a bath containing water is good enough to risk." If it is desired to use the direct current from the main in the full-length bath, the safest way is to use the motor generator like that supplied on the "Pantostat," etc.

At St. Bartholomew's the direct current is not supplied to any of the full-length baths, the alternating (sinusoidal) current being used instead. As explained before, the inclusion of a static transformer removes all risks of short circuits to earth (see Fig. 25). After the current has been switched on and regulated, the patient requires no further attention. There has been no accident or failure since the baths were first installed. Another advantage of this freedom from risk is that continued attention to the patient while in the bath is not necessary—an advantage which is specially to be considered in busy hospital practice.

SUPPLY FROM PRIVATE INSTALLATION

Where current from the main is not available some other source of supply must be sought.

If it is intended to use electricity for all its medical purposes, the best plan is to install a dynamo and drive it by means of a gas, oil or steam engine, or even a water turbine, if such power is available. The current could be used direct, but it would be found more convenient to charge accumulators with it and use the current from them. In this way the engine need only be run for a few hours on two or three days a week, and the current will be available at all times. Where space is a consideration, a very compact little plant can be obtained, composed of a petrol engine, such as used on motor bicycles, coupled direct to a dynamo suitably designed for the purpose. A set to give 15 amperes at 60 volts meets most medical requirements in a private practice or small hospital, and runs very satisfactorily. In all cases the dynamo should be provided with slip rings, so that alternating current can be obtained when necessary.

While the upkeep of a small private plant as above indicated is not very costly, the initial outlay may prove an insurmountable obstacle. If there is a place in the neighbourhood where cells can be charged, then accumlators may be used.

SUPPLY FROM ACCUMULATORS

The construction and mode of action of accumulators is described on page 352. Accumulators provide a current of low voltage and high amperage, and are therefore particularly suitable for heating cauteries and lighting lamps. They can be readily obtained, packed in portable cases. Two to four connected in series will be sufficient for cautery and light; and six will provide a current strong enough to work a small spark coil as well. The strength of the current that is required can be adjusted by a rheostat attached to the case. The current from accumulators can be used for applications to the body, but as a higher voltage is necessary to overcome the resistance of the body, a number must be connected in series. The weight of such a battery would be very heavy; it is therefore more usual to use a battery of cells when a direct application of the current to the body is to be made. Such a battery is described on page 73).

A dozen 4-volt accumulators could be arranged to meet most medical requirements by means of a multiple switch, which would put them all in parallel, for cautery or light, and all in series for direct application to the body—with a shunt resistance.

Even if he has access to a main supply, a medical practitioner may require accumulators for use away from home for heating cautery instruments or lighting exploring lamps or for working a portable X-ray apparatus in houses where there is no main supply.

To Charge Accumulators.—When charging an accumulator the current used for the purpose must not exceed the strength specified on the label affixed to the case, otherwise the accumulator will be damaged. When a *direct* current is supplied on the main, a current suitable for charging may be obtained from a lamp-holder or wall plug. The current is made to pass through a resistance lamp on its way to the accumulator so as to reduce its strength to the correct amount. The lamp to be used will depend on the voltage of the main current and on the charging current required. A higher candle-power lamp has a lower resistance and will let a stronger current through from the main to the accumulator. A lower candle-power lamp has a higher resistance and will let through a weaker current. If the voltage of the main current is high it will drive a stronger current through the same lamp than if it is low. If the voltage of the main current is 100 a 16-candle-power carbon filament lamp made for this voltage will allow a current of about 0.6 ampere to flow through the accumulator. Higher candle-power lamps will let a stronger current pass.

Special plugs are made with lamp-holders attached. A double flexible conductor is connected to this plug, and the free ends of the conductor are for attachment to the accumulator terminals. The plug is inserted into the wall socket, a lamp of correct candle-power attached to the holder, and the free ends of the conductor tested to find which is positive and which is negative. This can be done by means of a piece of moistened litmus paper. On it are laid, side by side, the free ends of the conductor without touching. The negative end stains the litmus blue. This end is to be attached to the negative terminal of the accumulator, the other end to the positive terminal. The accumulator will be charged to its full capacity when bubbles of gas are seen to escape freely from the plates and the acid assumes a turbid appearance. As the resistance lamp glows with almost its full candle-power, there is no reason why it should not be arranged to take the place of one of the lights regularly used in the house. In this way, charging of the accumulator costs practically nothing.

When a number of accumulators have to be charged at the same time a stronger current is required. Higher candle-power lamps must be used or two or more lamps can be connected in parallel. It is advisable, when a strong charging current is required, to have a board constructed with lamp-holders and switch attached. The number of lamps and their candle-power must be arranged so as to suit the voltage of the main current and the strength of the charging current required.

When an alternating current is supplied on the main it can be used to charge accumulators if an aluminium rectifier (p. 62) is inserted in the circuit containing the lamp and the accumulators.

SUPPLY FROM PRIMARY BATTERIES

If none of the sources previously mentioned are available, the supply may be obtained from primary batteries. Dry cells are now almost always used. Batteries of these cells packed away in wooden cases are now extensively used, and by reason of their portability, cleanliness and freedom from risk of shocks by short-circuiting to earth, are convenient for those for whom a main supply of current is not available. The cells will last from one to two years with average use, before it is necessary to replace them by fresh ones.

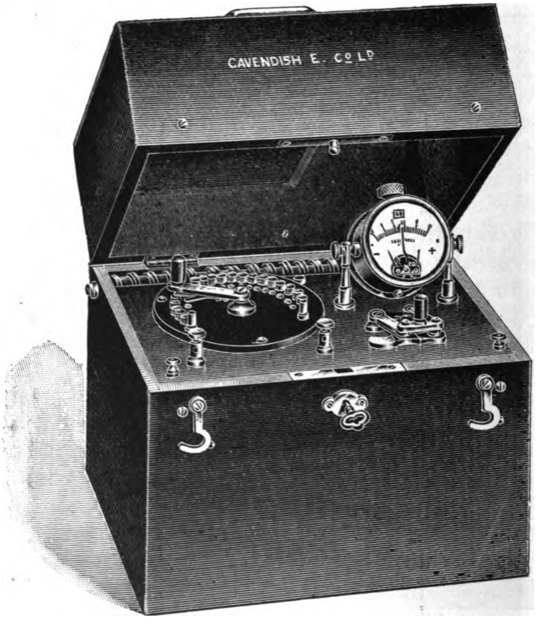

Fig. 29.—Portable Dry Cell Battery.

Primary batteries of dry cells will provide a current suitable for application to the body, as for electrolysis, and ionic medication, and for the lighting of *very small* lamps. The amperage of the current is not sufficient for heating cauteries or driving spark coils for X-ray work or high frequency. For these purposes batteries of bichromate cells (page 353) are suitable. Such batteries can now be obtained in portable cases. They are heavier than the dry-cell batteries and require more frequent recharging, although the owner can recharge them himself if he has a stock of potassium bichromate and sulphuric acid.

Portable Dry Cell Batteries.—These batteries can be obtained from the instrument-maker. The number of cells that they should contain will depend on the purpose for which the current is required. A battery of 32 will be suitable for almost all cases for which the direct application of the galvanic current to the body is desired. Fig. 29 shows such a battery. The case also contains a milliamperemeter, a current reverser, and a "cell-collector." By means of the latter, the strength of the current can be increased or diminished by including a larger or smaller number of cells in the circuit.

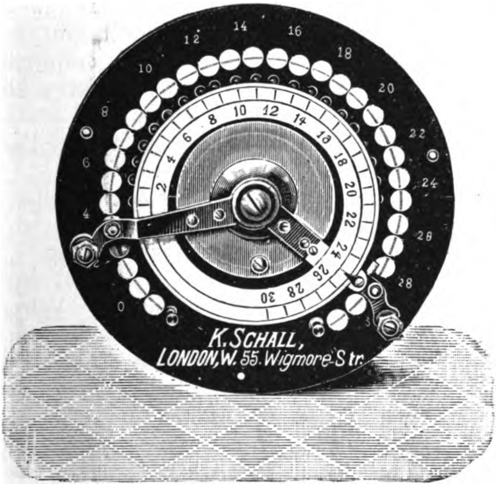

FIG. 30.—Double Cell Collector.

Cell-collectors are of two kinds, single and double. A single collector is shown in the portable battery illustrated in Fig. 29. It consists of a disc made of non-conducting material such as ebonite. Pivoted in the centre of the disc is a metal arm, and around the circumference is arranged a number of brass studs. When the metal arm is rotated it makes contact with the studs. The positive pole of the first cell is connected with the stud marked O, and the negative pole of the last cell is connected to the stud marked 30 (assuming that there are 30 cells in the battery). The cells are joined up in series, and a wire connects each junction with a stud. The junction between the first and second cells is connected to the stud marked 1; the junction between the second and third cells is connected to the stud marked 2, and so on.

The stud marked 0 is connected also to the + terminal which delivers the current to the patient, while the — terminal is joined to the rotating arm.

Now when the rotating arm is in contact with stud 0, no current can pass to the patient. When it is moved on to stud 1, one cell will be included in the circuit. When it is moved over the other studs, the number of cells included is indicated by the number on the disc with which the arm makes contact.

With this collector, the first few cells are used with every application of current, while those at the other end of the series are used only when the strongest current is required. Hence the first few cells are soonest exhausted and then they form a useless resistance for the current from the other cells to traverse.

The double collector, Fig. 30, is an improvement on the single collector, enabling any groups of cells to be used at will. It has two metal arms mounted on the same axis but insulated from each other. One arm is connected to the positive and the other to the negative terminal. Either can be placed on any stud. If they are placed on adjacent studs, one cell only will be included in the circuit. The further they are separated the larger the number of cells that can be included. An index is fitted to one of the arms and shows at a glance the number of cells in action at any moment. Next to the shunt resistance, it is the best method of controlling the current from a battery of this kind.

The current collector does not allow absolutely even regulation of the current. The current increases abruptly step by step as cell after cell is taken into the circuit; these sudden increases cause pain when sensitive parts, such as the sockets of the teeth, are subjected to them, but are not felt when the current is passed through the skin in less sensitive parts. It will be noted, if the cell-collector is examined, that the rotating arm passes on to the next stud before it quite leaves contact with the preceding stud. If this did not happen, the current would be completely switched off before the next cell was taken into the circuit, and violent shocks might be caused when a patient was receiving the current. The operator must, however, not leave the rotating arm in contact with two adjacent studs. If this precaution is neglected, the cell included between the adjacent studs will be short-circuited and soon exhausted.

A shunt resistance would allow a more even regulation of the strength of the current. The cells are joined together in series and the current from the total number is passed through a rheostat. The current for the body is shunted off from the rheostat and its strength is regulated by moving a slider along the latter, the method being the same as that adopted for the regulation of the direct current from the main.

Leclanché Cell Batteries.—If the medical practitioner frequently desires to use a constant current for ionisation, electrolysis, etc., at his own house, and there is no main supply available, there is no reason why he should not permanently install a battery of Leclanché cells, and use the battery of dry cells only when he has to apply the constant current away from home. The current that is derived from cells is perfectly steady and unvarying, and more agreeable to the patient than that derived from small motor generators or even that supplied on the main from the large dynamo at the power station.

Forty cells joined together in series will provide an electromotive force of about 60 volts: that will be sufficient for most purposes. The current should be regulated by means of a shunt resistance.

The cells will require attention once every six months. Water lost by evaporation must be replaced then, and if the zincs are blackened they should be scraped clean and amalgamated. In the early days of the electrical department of St. Bartholomew's before a main supply was available, the direct current for therapeutic purposes was obtained from Leclanché cells. There were 3 batteries, each containing 50 cells.

CHAPTER IV

THE BODY AS A CONDUCTOR OF ELECTRICITY

Resistance of the Body.—When an electric current traverses the body, it encounters its chief resistance in its passage through the skin. The soft tissues and organs underneath oppose its flow to a much less degree. The resistance of the skin varies within wide limits, while that of the underlying parts, though not the same for each organ, remains relatively constant for each. The explanation of these facts will be apparent when it is remembered that the conductivity of the tissues is due to the presence of ions. The skin is poor in ions, their number varying considerably, according to the condition of the skin; the underlying tissues and organs contain an abundance of ions, and their proportion is relatively constant.

The outermost layer of the skin is the horny layer, and if it is quite dry, and if the electrodes in contact with it are dry metal, there will be no ions to conduct the current through the skin. If this current is the constant current and at a voltage not higher than that at which it is usually applied for medical purposes (say 50-70 volts), it will be unable to overcome the resistance of the skin and no current will flow. If, however, the sweat glands secrete, the dry horny layer will be moistened and contain ions, and some current will flow. If the skin is moistened with salt solution, as is customary before applying the electrodes, its resistance is artificially reduced, by reason of the diffusion, into the horny layer, of water containing ions.

The resistance of the body will vary also according to the size of the electrodes; if the latter cover a large area of skin there will be a large area of entry for the current and the resistance will be lower. The distance between the electrodes will also influence the resistance; the longer the path for the current, the greater the resistance, and vice versa.

It will be seen, then, that the resistance of the body depends upon a number of factors and can vary within wide limits. If the constant current is used and is sent from one hand to the other, along the upper extremities and across the trunk, the hands being immersed in salt solution, the resistance may be taken as about 1300 ohms. When the resistance of the skin is excluded, the residual resistance is much less. Some experiments by Weiss showed that the resistance from shoulder to shoulder was 40 ohms, and from elbow to elbow was 250 ohms, when the skin resistance was excluded.

If the current is allowed to flow for some time and the metals of the electrodes be separated from the skin by pads soaked in salt solution, ions will actually migrate into the skin, and the resistance of the latter will progressively diminish, till it reaches its lowest value at the stage when it is permeated with ions. The phenomenon will be frequently observed during the process of medical ionisation; the needle of the milliamperemeter will be seen to move gradually across the scale, showing that the strength of the current is increasing owing to the diminution of the skin resistance. If, however, the moistened pads contain ions that will form insoluble compounds when they come in contact with ions in the skin, the reverse will take place; the needle will move in the opposite direction, showing a fall in the current strength. The resistance of the skin has increased because the number of ions in it has diminished.

The thick skin of the palms and soles has a higher resistance than the thinner skin elsewhere. Patients who have been long confined to bed have a high skin resistance, because the horny layer is less readily shed and therefore thicker.

The body offers less resistance to currents that are alternating or intermittent, flowing for very brief periods in any one direction before interruption or reversal. Thus the resistance of the body is much less for faradic currents, and currents that alternate with a high frequency. The writer has measured the resistance of some hundreds of patients to the faradic current, previous to taking electrocardiographic records, and has found it to vary, in different individuals, from 500 to 700 ohms. The resistance was taken through the forearms, from elbow to elbow, the forearms being immersed in salt solution. The faradic and alternating currents do not alter the resistance of the skin like the constant current, because they do not cause a migration of ions into it.

The Voltage Required to overcome the Resistance of the Body.—From what has been said regarding the resistance of the body it will be evident that the voltage required to yield a measurable current must be higher for some parts than for others. If the free ends of two wires connected to the terminals of a single dry cell be placed side by side on the tongue without touching each other, a current will flow through the tongue and a salt taste will be experienced. The voltage of the dry cell, though very low, is able to cause a current to flow through the tongue because the resistance of the mucous membrane is low. The resistance of the mucous membranes is much lower than that of the skin, even though the epithelium may be of the same type. The reason is the constant moistening of the former by the secretion of glands, and, consequently, the prsence of abundance of ions. If the ends of the two wires are placed on the *skin* no current will be felt and no current will be indicated by the milliamperemeter because the resistance of the skin is too high.

From what has been said regarding the widely varying resistance of the skin it will be evident that the voltage required to yield a current will depend upon the state of the skin, whether dry or moist, thin or thick. It will depend also on the strength of the current required; the stronger the current, the higher must be the voltage.

Path of the Current in the Body.—When the current has passed through the skin it encounters much less resistance in the underlying tissues. The path of least resistance will be the shortest path between the electrodes, and more of the current will pass that way, but some will take more circuitous paths, because, being presented with several paths, it will distribute itself between them, the amount going by each one being inversely proportional to its resistance. Some of these paths will loop out to each side (Fig. 31) beyond the parts enclosed between the electrodes, and the amount of current flowing along these paths will be less as the loops become wider and the paths between the electrodes become longer. It will be evident then that the deeper a tissue lies the smaller will be the share that it will receive of the whole current passing between the electrodes. The *density* of the current (that is, the amount of the current traversing a unit of sectional area at right angles to its path) will be

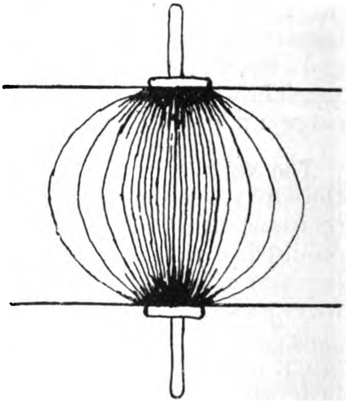

Fig. 31.—Diagram to indicate divergent lines of flow of constant current through tissues, with greatest density of current immediately under electrodes.

greatest at the points of its entry and exit, and least at a point half-way between. If, however, the electrodes are large, and equal in area to that of the cross section of the path of the current, there will be no reduction in density.

If we imagine the current of electricity to be made up of thin lines or strands we may conceive these lines to be gathered together as in a cord, in the regions where the density of the current is greatest. If the cord is frayed out the density is less but the same number of lines are there. In its passage from one electrode to the other no lines are lost, but some of them will take a very circuitous route before being finally gathered in at the other electrode. If one electrode is larger than the other, the density will be greater at the smaller electrode. A certain minimum density of current is necessary to produce appreciable physiological or therapeutical results, and one may safely say that with the currents used in medical electricity the density in the outlying regions away from the parts included between the electrodes is so slight that the current will have little or no therapeutic effect.

If both electrodes are placed on the same side of the trunk or a limb, the lines of flow of the current will dip down into the deeper parts(Fig. 32), but the density of the current will be greatest under the electrodes and in the superficial parts, but very slight in the deeper parts. Very little current will travel *in* the skin itself between the electrodes on account of its high resistance. If the electrodes are placed on the same side, but farther apart, more of the current will flow through the deeper parts than if they are placed closer together (Fig. 33). The closer the electrodes are placed together on the same aspect of the trunk or a limb, the shorter becomes the direct path between them, in proportion to the divergent paths into the deeper tissues; and the larger the proportion of the whole current that flows along the direct path and the smaller along the paths through the deep tissues. When the electrodes are very close together, the distance between the opposing edges is considerably shorter than that between the edges which are furthest apart, and when the current flows, the so-called "edge effect" is noted; that is, the current produces its maximum effect in the tissues which lie in the region of the closely opposed edges, while very little effect is produced in the parts where the edgs are at the maximum distance from each other.

On its passage through the tissues more of the current will flow along the parts which present a lower resistance. The blood and lymph contain ions in abundance so that the more vascular organs conduct more of the current than the less vascular organs such as bone.

It is very necessary to remember that the current does not confine itself to the direct path between the electrodes but distributes itself between all the tissues in inverse proportion to their resistance and the length of the different paths. If it is desired to stimulate a nerve which lies immediately under the skin, a relatively weak current is required. If the nerve lies deeply, it will be traversed by only a small portion of the current, because the lines of flow of the latter have diverged considerably; and a much stronger current must be passed in order that the portion of it which the nerve receives may be great enough to stimulate the latter. If the electrodes are placed side by side on the skin over a deep-lying nerve, the latter will receive an infinitesimally small portion of the current, and if they are placed close together and a strong current used, the edge effect will be pronounced and the skin may be damaged. If, therefore, the tissue or organ which is to be traversed by the current lies in any but a superficial position, the electrodes should be placed on opposite aspects of the body so as to include the tissue or organ between them. The deeper the tissue or organ, the stronger must be the current that is taken into the body in order that the deep parts may receive an adequate portion of it; and the larger must be the electrodes, in order that the skin may not receive a greater density of current than it can tolerate.

If it is wished to direct a current through a joint, the best plan is to place the electrodes on opposite aspects, but the edges must not be brought close together, otherwise the edge-effect will be produced. If the joint is encircled by a single electrode, and the other electrode placed at a distance, more of the current will pass along the extra-articular region. If both electrodes encircle the limb, one above and the other below the joint, more current will pass along the extra-articular tissues, and if they are placed close together, the edge-effect will be produced.

Current Density.—It will be understood, from what has been said above, that the value of the current, as measured by the milliamperemeter, is no indication of the current passing through any one part of its course. The instrument measures the current passing through the parts of entry and exit and through the body as a whole. The amount of current passing into and out of the body is no index of the physiological action of the current or the therapeutic effect it is likely to produce, unless we know also its *density*. The same strength of current when "concentrated" in its passage through a small electrode will produce a greater effect in the skin than when it passes through a large electrode. The density of the current in the underlying organs cannot be measured, but the density in the region of the electrodes can be easily calculated and is a much more accurate measure of dosage than the strength of the current. There is no named unit of density, but a knowledge of the number of milliamperes per square centimeter would give a more accurate measure of dosage or stimulation than the number of milliamperes alone.

The divergent path that has been described is that taken by the constant current, and, presumably, by the faradic, sinusoidal and other low-frequency alternating currents. Currents which alternate with *high-frequency* (the so-called high-frequency and diathermy currents) travel almost entirely on the surface of *solid* conductors. In electrolytic conductors (*i.e.*, fluids containing ions) they do not show this preference for the surface layers. In the human body, which is an electrolytic conductor but extremely complicated by the presence of numberless vessels containing moving fluids, the path has not been experimentally ascertained. It is not restricted to the surface. The major portion of the current flows along the direct path between the electrodes. Whether it also diverges

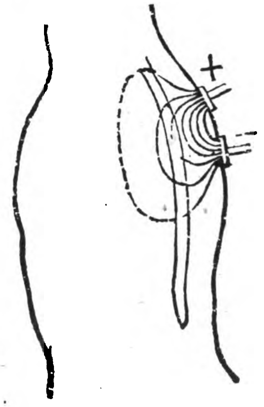

FIG. 32.

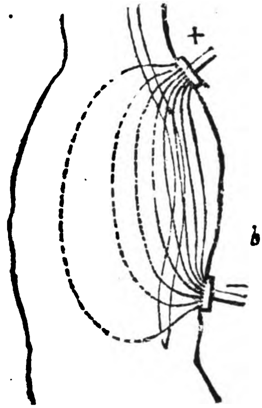

FIG. 33.

into outlying paths is uncertain. The density of the current is greatest along the shortest path between the electrodes.

Anode and Kathode.—The anode is the electrode by which the current passes *into* the body (it may be remembered as the "in-ode"); the kathode is the electrode by which the current passes *out* of the body. In physiological experiments, in which we use excised muscle and nerve and place the electrodes in actual contact with them, the current is confined to them and there is one anode and one kathode, each localised to the point of contact of electrode with tissue. In the case of the body the conditions are quite different, and it is impossible to place the electrode or electrodes in actual contact with the muscle or nerve which is to be stimulated, but only at a distance from them, with the skin and fasciæ intervening. Further, the muscle and nerve are not isolated, but in contact with tissues on all sides. These tissues all conduct the current, and it is therefore impossible to localise the current to the muscle or nerve or to localise anode or kathode to the region immediately under the electrode. There will be, instead, a number of anodes and kathodes scattered over the surface of the muscle or nerve. Fig. 34 shows, diagrammatically, an anode overlying, but not in contact with, a muscle that is below the

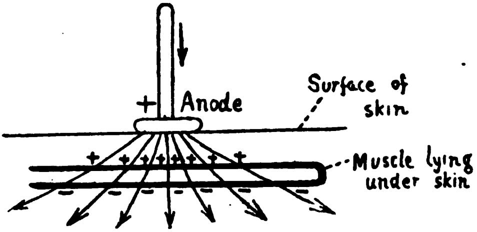

FIG. 34.

skin. It will be seen that on the side of the muscle facing the electrode there are a number of anodes, and a number of kathodes on the side away from the electrode. The current density will be greater on the side facing the electrode, so that when the latter is, say the anode, we are influencing the muscle not with an entering current only, but with a leaving current as well, the former, however, being at a greater density than the latter.

It has been mentioned earlier that it is not possible to procure pure anelectrotonus or katelectrotonus in the nerves or muscles of the intact body. The reason is evident from what has been stated above.

Conduction of Currents at High Voltage.—The voltage at which the constant current can be applied to the body for medical purposes is not high and the current is dependent on the tissue ions for its conveyance through the body. If, however, the voltage is very high, as is the case with static electricity, the tissues are able to conduct the current like solid conductors, from atom to atom as well as through the agency of the ions.

CHAPTER V

IONIC MEDICATION

Definition.—It has been shown in Chapter I. that the results that follow the application of the constant (galvanic) current are to be attributed to the behaviour of the ions as they conduct the electricity. Ionic medication would, therefore, in its widest sense, include many of the branches of medical electricity, but the term is generally used for that form of treatment in which an electrical current is used for the purpose of introducing the ions of soluble medicinal substances into the body. The term "kataphoresis" is occasionally used instead of "ionic medication," but it should be reserved for another physical phenomenon that occurs during the passage of the current through the tissues—viz., the gradual passage of water from the region of the anode to the region of the kathode. Kataphoresis plays no *essential* part, so far as is known, in the process of ionic medication.

The Use of the Electrical Current for Introduction of Ions into the Body.—There is enough experimental evidence to prove that ions can be carried into the body by the electrical current. The lithium ion and the iodine ion have been made to pass through the skin and have been detected in the urine and saliva. The strychnine ion can be made to pass through the skin of an animal and cause convulsions, and the cyanide ion (CN) can be similarly introduced and cause rapid death. The entry of these poisonous substances is not by diffusion, because control animals with pads soaked in solutions of strychnine hydrochloride or potassium cyanide in contact with the skin are not affected if the current does not flow, nor are they affected if the current flows and the pads are connected to the wrong poles of the source of current. Cocaine ions may be made to pass into the skin and cause local anæsthesia. Here again the anæsthesia is not developed so long as the current does not flow.

Another good illustration of the power of the current to cause the ions to penetrate is seen when an ulcer is treated by zinc ions. The application of a dilute solution of zinc sulphate to the granulations at the base and edges produces no result that is visible to the eye. But if the solution is connected to the positive pole of a source of constant current, and the latter allowed to pass for ten minutes, the granulation tissue acquires a pearly white colour, not only on the surface, but in the deeper parts. This white colour is due to the formation of a compound of albumen and zinc. The zinc ions have entered, and many have entered into combination with the proteins.

Advantages of the Ionic Method.—The method of introduction of drugs, or, more correctly speaking, their ions, by the electrical current has special advantages which are possessed by no other method. The current passes into every part of the tissue that is to be treated, and the ions travel along the same paths. Suppose, for example, an infected ulcer is to receive treatment by an antiseptic, such as zinc sulphate. If a solution of this salt is placed in contact with the ulcer, it will exert its germicidal action only on the surface, because it can penetrate only by diffusion, which process is very slow. If, however, the solution is conected to the positive pole of a battery, the zinc ions are now carried into the tissue. Every part with which the solution makes contact will be penetrated by the electrical current, so that all the cells and their intercellular spaces will receive the zinc ions. There is the further advantage that by using the electrical current, only the therapeutically active ion is taken in. In the case of zinc sulphate and the infected ulcers, the zinc ion, only, is taken in, and the SO_4 ion passes in the opposite direction. The refusal of some chronic ulcers to heal when germicidal solutions are placed in contact with them in compresses, and their prompt response and progressive healing after the introduction of the ions by the electric current, is frequently noticed by those who have experience of the ionic method of treatment.

Another advantage of the method is that the ions are introduced only into the region where they are wanted. If a drug is taken by mouth it is absorbed into the blood and is distributed to all parts of the body, and here again when it passes through the capillary walls it has to diffuse into the cells. By the ionic method it is taken in by the current.

Limitations of the Method.—The use of the electric current for the introduction of ions has this limitation—only the more superficial tissues receive them in numbers sufficient for therapeutic action. The deeper the part that requires treatment, the smaller the number of ions it receives. The reasons for this are the following. In the first place, the current, in its passage through the skin and into the tissues, does not confine itself to the shortest path between the points of its entry and exit, but, in addition, takes divergent paths into the deeper parts. The ions take similar divergent paths and so spread farther apart as they penetrate the deeper tissues. In the second place, the circulating fluids carry away many of the ions. After they have passed through the stratified squamous epithelium, the ions encounter capillaries and lymphatics in the dermis and its papillæ. Some will migrate through the walls of these vessels and then be carried away by the circulating fluids. Some will miss the most superficial vessels but cannot penetrate far without meeting other vessels that lie at deeper levels. All the ions will be carried away sooner or later, and it is unlikely that any will reach a greater depth than a few millimetres. In the third place, if the ions of heavy metals are being introduced, they come in contact with other ions in the tissues with which they may unite and form insoluble compounds. The latter can pass no further. The silver ion, for example, on meeting the chlorine ions in the tissues, forms the insoluble silver chloride. When, therefore, silver ions are introduced, most of them form silver chloride on account of the abundance of chlorine ions in the tissues, and further migration is impossible.

The fact that symptoms arising from disease of deep-lying tissues are often relieved by introducing ions from without, is no proof of the entry of these ions into the diseased parts. Many observers claim equally good results when ions of neutral substances, such as sodium chloride, are used instead of the ions of drugs for the treatment of disease of parts situated more deeply than a few millimetres.

When ions are introduced for the treatment of parts which lie beneath the skin, it cannot be expected that many will penetrate below the deep fascia. Structures which lie immediately below the latter may receive some ions, but if there is a layer of adipose tissue under the skin the deep fascia may not be reached, on account of the greater distance which the ions have to travel.

The method of action of the current in the treatment of disease of regions beyond those which the ions can reach, will be considered in Chapter VII.

Conditions on which the Depth of Penetration of Ions Depends.—The depth to which an ion will penetrate depends, first, on the duration of the flow of the current; the longer the period of flow the greater the depth of penetration. Secondly, on the electro-motive force at which the current is supplied—a greater electro-motive force will drive the same ion farther, in the same time, than a lower electro-motive force. Thirdly, on the ion; those composed of elements of low atomic weight will penetrate farther than those of which the component elements have a high atomic weight, the time of current flow and the electro-motive force being the same for each ion.

Physical experiments have been performed to determine the actual depth of penetration of ions into non-living material. An electrical current was made to traverse a jelly containing sodium and chlorine ions (to make it a conductor) and take in with it hydrogen ions from a solution of hydrochloric acid. The depths to which the hydrogen ions migrated was indicated by the decolorisation of the phenol-phthalein with which the jelly was tinted. The hydrogen ion was found to have travelled 10·8 mm. in one hour, with an expenditure of 1 volt of E.M.F. along each centimetre. Sodium travelled 1·26 mm. in the same time, potassium 2·05 mm. and chlorine 2·16 mm. With an expenditure of 10 volts along each centimetre the distances are ten times as great.

In the case of the tissues of the body the conditions are different, and, such as they are, diminish the depth of penetration. The lines of flow of the current diverge and the ions therefore pass laterally as well as directly forward; other ions enter the blood and lymph streams and are carried away; others combine with tissue ions and may form insoluble compounds and therefore pass no farther. The depth, therefore, to which ions penetrate into the tissues is not the same as for inert simple substances, like the jelly in the experiment described above, and is probably less, and cannot be calculated from the factors given above. An experiment by Gautier showed that a current of 20 milliamperes was able, in ten minutes, to take copper ions into and through the wall of the uterus of a rabbit. The wall was one millimetre in thickness. Finzi introduced ferro-cyanide ions through the skin over the knee joint of a monkey, and using a current of 10 milliamperes for thirty minutes, was able to detect the ions in the cartilage of the joint.

Apparatus required for Ionic Medication.—For the practice of ionic medication we require: (1) A source of electric current. (2) Cables to conduct the current to the body. (3) Electrodes to lead the current from the cords into the body, and, at the same time, hold the solutions of the drugs, the ions of which are to be introduced. (4) Solutions of the drugs.

(1) *The Source of Current.*—Chapter III. is devoted to a description of the sources of supply of current for medical purposes. The current must, of course, be a *constant* current. It should be possible to regulate its strength between zero and a maximum, which, when the body is in circuit, and the conditions are those under which ionic medication is carried out, should reach a value of 100 milliamperes at least. To send such a current through the body an E.M.F. of at least 50 volts is necessary, though for a smaller current a lower voltage will do.

The constant current is sometimes called the *continuous* or *galvanic* current, and when obtained from the main is known as the *direct* current, or, for short, DC.

If the current from the main is available, and if it is a *direct* current, this will be the most useful and economical. Although the voltage of this current, as supplied for domestic purposes, is too high for medical purposes, it can be suitably reduced, and the method of doing so is described on page 47 *et seq.* There is no risk of shocks to the patient or operator if the precautions detailed on page 66 *et seq.* are taken.

If there is no main supply, much can be done with a portable battery of dry cells, or a permanently installed battery of Leclanché cells. These batteries are described on page 73. Where there is private plant for generating electricity, the current required may be taken direct from the dynamo. Or the dynamo may be used to charge accumulators. The current may then be taken from the latter when required. In this way the dynamo need be worked only on occasions when convenient.

If accumulators are used, a number of them must be connected in series, so that the voltage of the current may be sufficiently high to overcome the resistance of the body.

(2) *The Cables* that conduct the current to the body should be made of flexible stranded copper wire covered by insulating material. It is essential that the latter should be waterproof, because it is certain that they will be accidentally wetted sooner or later, and then the copper will gradually corrode and break. Further, the wire is no longer insulated where it is wetted, and if it should touch the patient's skin the current will pass out and form an additional circuit and perhaps cause blisters at the point of contact. A flexible stranded copper wire with its ends securely soldered into firm metal end-pieces of larger diameter may be enclosed within a narrow rubber tube; the free ends of the latter are stretched over the end-piece, making a waterproof covering of the soldered joint, but leaving the end free, so that it can be fixed to the binding screw of electrode or battery. Cables of this kind have been used during the past few years in the electric department of St. Bartholomew's and have proved to be very satisfactory.

(3) *The Electrodes.*—The electrodes consist of two parts: (*a*) an absorbent pad, which is soaked in the solution containing the ions; (*b*) a metal plate or sheet of metal gauze of rather smaller area than the pad and bearing a binding screw for attachment of the cables.

The pad that contains the solution should be made of absorbent material, such as lint, glass cloth, towel or Gamgee tissue. It should be of a thickness corresponding to sixteen layers of lint. Separate strips or layers can be placed one over the other, or a large sheet may be folded and refolded till it has the desired thickness.

The metal plate, to which is attached the cable, may be made of sheet brass. Aluminium may be used, but is more likely to break after much bending. The metal plate may be placed direct on the pad, but if a layer of felt is placed between, the layers of lint may be reduced to eight. The felt should be a quarter of an inch thick, and it should be of larger area than the metal, so as to overlap it half-an-inch all round. The felt should be stitched to the metal, and, for this purpose, the edges of the plate should be perforated for the passage of the needle and thread. An alternative method of attaching the plate to the felt is to stitch two bands of tape by their ends to the edges of the felt, one near each end. The metal plate can then be slipped under them and so kept in position. The felt can then be detached and replaced as frequently as desired and the time occupied in stitching and unstitching is saved. If it is preferred to secure the felt to the plate by stitches, the metal need be drilled only at the corners and, if the plate is large, at the middle of each edge as well. These felt-covered metal plates are useful for other electro-medical purposes also.

An electrode is shown in section in Fig. 35. When the pad has to be applied to a part of the body with an irregular surface, such as the ankle, the metal plate should be replaced by flexible copper gauze. This can be easily bent to the desired surface. It may be necessary to use not a single piece but two or three narrow strips as, for example, when a flexed elbow is to be ionised and the joint cannot be straightened. To connect the cable to the gauze, a safety pin, with a binding screw soldered to it, is passed through the gauze and the cable secured to the screw.

To ensure perfect contact of the pad with the skin of irregular surfaces the lint should be applied in strips. The whole thickness of the pad should then be composed of lint, and the felt not applied.

If a finger or toe is to be ionised, a band of lint of the same width as the length of the finger or toe may be wound round, and a piece of copper gauze applied round the lint. Adjacent fingers or toes should be screened off by waterproof.

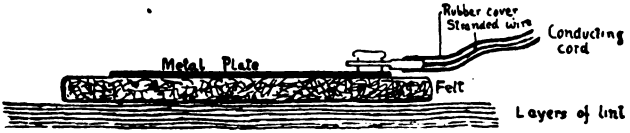

FIG. 35.—Diagram of Electrode.

The electrodes described above are intended for application to the unbroken skin. For wounds, ulcers, sinuses, and for less accessible parts special electrodes are required. They are described later (page 104 *et seq.*).

When the electrode is in position the pad is in contact with the skin, and the felt, with the metal, rests on the pad. It will be seen that with this arrangement the metal is situated some distance off the skin. The importance of this will be evident when it is recollected that, as described in Chapter I., new ions possessing caustic properties are formed at the points where the solid and the fluid conductors are in contact. At the metal plate of the electrode that forms the *kathode,* $\overset{+}{\mathrm{Na}}$ and $\overset{-}{\mathrm{OH}}$ ions are formed. The latter are repelled from the kathode towards the skin. If the pad and felt are thin, they will finally reach the skin, and, being caustic, will, if in sufficient concentration, cause burns. In the case of the anode, ions of the metal forming the plate lying on the absorbent pad will migrate towards the skin. If the pad is thin they will soon reach it. In some cases it is intended that the ions of a metal shall be introduced, but not necessarily those of the metal forming the electrode (copper and zinc when the electrode is made of brass). In other cases, positively charged ions other than those of metals (quinine ions, for example) are to be introduced, and in these cases the ions of the metal forming the electrode are not desired. A pad like that described is sufficiently thick to hold sufficient solution and an ample supply of the ions to be introduced. At the same time the ions of the metal part of the electrode will not have time to reach the skin as the pad is sufficiently thick.

(4) *The Solutions* need not be more than 1% in strength. It must not be thought that more ions will be introduced if the solution is stronger. The stronger the solution the larger the proportion of undissociated molecules. Stock solutions of 10% strength may be made and diluted with ten times the bulk of warm water when required for use. Tap-water may be used if it is not "hard." If it is hard, and contains much carbonate or bicarbonate, precipitates will be formed if it is used to dilute zinc salts. To allow for this, the zinc salt may be diluted rather less, or distilled water may be used. The ions present in the tap-water will be introduced at the same time, but there is no evidence that they produce any appreciable effect.

In some cases the substance to be introduced need not be already in the ionic state before the current is passed. For example, if the zinc ion is to be introduced, we may use the metal itself instead of a solution of one of its salts, and connect it to the positive pole. When the current flows, the metal slowly passes into solution, so that its ions are formed. Those ions then migrate into the tissues. It is more convenient to use the metal when parts difficult to reach with the solution—*e.g.*, sinuses—have to be treated by the ionic method.

The Ions used in Medicine.—These may be arranged in two tables, according to the charge which they bear. Against each ion is placed the salt from which it may be most conveniently obtained, the strength of the stock solution, and the properties possessed by the ion.

Ions with — Charge (known sometimes as "Anions")

Chlorine ($\overset{-}{\mathrm{Cl}}$). From solution of common salt. (The salt is best stocked in the solid condition, and a solution of three teaspoonfuls to a pint of water made when required). The chlorine ion is used for its power to soften hard scars and loosen adhesions.

Iodine ($\overset{-}{\mathrm{I}}$). From solution of potassium iodide or lithium iodide (10%). This ion also possesses the properties mentioned above. It has been used successfully for syphilitic ulcers. If free iodine is dissolved in the solution of potassium iodide, an additional ion is formed. This possesses strong germicidal power, and can be used for chronic infected ulcers as well as syphilitic ulcers.

Salicylic ions. From solution of sodium salicylate (10%). These ions possess analgesic properties (see below, under Quinine).

Ions with + Charge (known sometimes as "Kations")

Zinc ($\overset{+}{\mathrm{Zn}}$). From a solution of zinc sulphate (10%). This ion possesses germicidal properties. When concentrated they produce caustic action.

Magnesium ($\overset{+}{\mathrm{Mg}}$.) From a solution of magnesium sulphate (10%). This ion is often successful in the removal of small multiple warts.

Lithium ($\overset{+}{\mathrm{Li}}$). From a solution of lithium chloride (10%), or lithium carbonate. (The latter is only slightly soluble). Lithium ions are believed to be able to cause solution of deposits of urates. They have been used for treatment of gouty arthritis, but the passage of the current without these ions produces equally good results.

Silver ($\overset{+}{\mathrm{Ag}}$). From a solution of silver nitrate (10%). (Distilled water should be used.) These ions have been used for ulcerative colitis and gonococcal infection. They penetrate a shorter distance than other ions, on account of the formation of very insoluble salts as soon as they gain entry.

Copper ($\overset{+}{\mathrm{Cu}}$). From a solution of copper sulphate (10%). This ion possesses properties similar to those of the zinc ion.

Mercury ($\overset{+}{\mathrm{Hg}}$). From a solution of mercuric chloride (10%). This ion has been used successfully for some cases of syphilitic ulcer.

Quinine. From a solution of quinine hydrochloride (10%). This ion possesses analgesic properties, and, like the salicylic ions, is used in the treatment of painful neuritis. It is, however, doubtful whether, in successful cases, the relief is due to these ions.

Cocaine. From a solution of cocaine hydrochloride (10%). This ion produces long-lasting but superficial anæsthesia. The synthetic and not the natural cocaine should be used for making the solution.

Adrenalin. From a solution of adrenalin chloride (1 in 1000). This ion is used, with the cocaine ion, for producing vaso-constriction at the same time as local anæsthesia.

Morbid Conditions and Regions suitable for Ionic Treatment.—It is especially for inflammation of the skin or mucous membranes due to bacterial infection, with or without ulceration, that the ionic method of treatment is indicated. Cases which do not heal quickly under treatment by simple methods should receive ionic treatment. The skin and the mucous membrane of the mouth, nose, middle ear, rectum, lower part of colon, urethra, vagina, cernix, and uterus are accessible for treatment. The antrum of the maxilla and the Eustachian tube can also be reached. The cornea and conjunctiva can also be treated by the ionic method. The parts which lie immediately under the skin may be treated by the ionic method, but only the most superficial regions of these parts can be reached by ions in sufficient number to be of therapeutic use.

Practical Application.—If the part to be treated lies under the skin, the latter should be first freed from greasy secretion by washing with soap and water and then thoroughly rinsed. Or the skin may be wiped with ether or acetone. Any skin lesion should be covered by a scrap of waterproof material, such as thin sheet rubber or adhesive plaster. The pad, soaked in the solution, diluted to a 1% strength and sufficiently wrung out, so that it does not drip, is placed on the grease-free skin, so as to make good and even contact all over. It is very important that there should be good contact all over. The metal with the attached felt is soaked in the same solution and placed on the pad, bent, if necessary, so as to make good apposition. The two are then securely fixed, by means of a bandage. The connecting cord from the battery is then attached to the metal plate binding screw. This is known as the "active" electrode.

In order to complete the circuit, another electrode is required. It is exactly the same as the active electrode, and it is soaked in salt solution. It is placed on some convenient part of the body, away from the active electrode. It should not be placed close to the active electrode for fear of producing the "edge-effect" (see page 84). In area, it should be equal to or larger than the active electrode, never smaller. It is known as the "indifferent" electrode.

Instead of attaching a pad as an indifferent electrode, an arm or leg may be immersed in the arm or leg receptacles of the Schnee bath, the carbon electrode being connected to the appropriate pole of the battery or other source of current.

If more than one part is to be treated, we may use *two* "active" electrodes, and place one over each part. A different ion will, of course, be taken in from each electrode, one electrode being positive, the other negative. The two active electrodes should be of the same area. Or, two or more active electrodes may be used, and one indifferent electrode. In this case two or more conducting cords will be required, one to each active electrode. The area of the indifferent electrode should be equal to or larger than the united area of the active electrodes.

The pole of the battery or other source of current to which the active electrode or electrodes should be attached depends upon the electrical charge of the ion that is to be driven in. Pads containing ions with the positive charge (kations) are connected to the positive pole of the source of current. Ions with the negative charge (anions) are placed in the pads connected to the negative pole.

When the circuit is completed the current is started. It must always be started from zero, slowly and gradually increased, a few milliamperes at a time, till the maximum is reached, at which it may stay for the period of the treatment. It is then gradually diminished till it reaches zero. The *sudden* increase of the current or its *sudden* decrease will cause the patient to feel a smart shock, and must be avoided. The too rapid increase in strength of the current, or the too rapid diminution, will cause pain without shock. Four or five minutes should be occupied in increasing the current to its maximum and in reducing it to zero.

When the current has reached a small value the patient feels a pricking, tingling sensation. It soon disappears, and as the current is further increased he begins to perceive a hot, burning sensation over the whole pad. This again diminishes, but when the current is increased beyond a certain value the sensation does not diminish, and the current should not be further increased. The maximum value should not exceed two milliamperes per square centimeter (*i.e.*, 12 per square inch). It is advisable, at the first application, to use not more than one milliampere per square centimeter. In most cases, one and a half milliamperes will be sufficient. If the patient persistently complains of burning pain localised to one spot, it may mean that excessive current is being concentrated there (owing to uneven contact of pad and skin, or uneven soaking of the pad), and the current should be slowly decreased to zero and the pad and skin examined.

It will be noticed that when certain ions are being driven in, the current, as indicated by the milliamperemeter needle, will show a spontaneous and gradual increase in its strength. This is because the saturation of the skin with ions reduces the resistance of the latter to the lowest value. On the other hand, other ions, like those of the heavy metals, form insoluble compounds with the tissue ions, so that the current-conducting ions are diminished in number and therefore the milliamperemeter needle moves back towards zero.

Ionisation of Ulcers and Wounds.—If the ions have to be introduced into a tissue from which the epithelium or superficial fascia has been lost, such as a wound or ulcer, any scabs or crusts should be first removed and the surface then swabbed with water or saline to wash away discharge. The pad should then be evenly applied to the cleaned surface. If the surface is very irregular, the uniform contact without leaving any part untouched may be secured by withdrawing, with a dissecting forceps, small flocculent portions of cotton wool from a roll, placing them in the crevices and irregularities till they are filled and a smooth surface obtained. The solution can then be dripped on to the cotton wool till the latter is moistened through, and then the lint pad can be applied.

Ionisation of Sinuses.—The ionisation of sinuses is more difficult, because it is less easy to ensure contact between the electrode and every part of the wall of the sinus. If the ions of zinc, copper or other metals are to be introduced, a rod of the metal, with a layer of cotton wool wound round it and soaked in a solution of a salt of the metal, may be inserted into the sinus down to its end. If the sinus is narrow, the uncovered metal may be used. An alternative method is to pass a fine brass tube, filled with some antiseptic solution, such as zinc sulphate (1 %), down the sinus to its end, attach a syringe filled with the same solution to the end of the tube, and force the solution from the end of the tube, at the same time slowly withdrawing the latter, but not completely. The tube is then passed again to the end of the sinus and the process repeated. By this method there is more likelihood of the solution coming into better contact with the wall of the sinus, and less chance of any part escaping contact with it. A terminal is attached to the tube, so that the latter can be connected to the battery or source of current.

When connected to the positive pole, zinc and copper ions migrate into the walls of the sinus. At the same time the metal of the tube gradually dissolves, forming ions, so that further ions (zinc and copper, from the brass) migrate into the wall.

An alternative method of ionising sinuses is to plug them with gauze soaked in the solution containing the germicidal ion. One end of the strip used to plug the sinus is allowed to remain outside. It is placed in contact with the metal end of the conducting cable. Care must be taken to prevent the metal or the end of the strip from coming into contact with the skin. For this purpose a piece of waterproof may be placed on the skin around the opening of the sinus.

The Ionisation of Less Accessible Regions.—Different methods have to be adopted if ions have to be introduced into less accessible parts.

Maxillary Antrum.—If the walls of the maxillary antrum are to be ionised, the cavity is first filled with the solution containing the ions (after a preliminary wash out with water), by means of a metal tube or catheter. The metal tube also serves to conduct the current into the solution within the cavity. It must be carefully insulated, except at the point where it is inserted into the cavity. Otherwise the current will pass into any other part with which the tube may happen to be in contact. The insulation may be brought about by sliding a rubber tube over the metal.

Rectum and Colon.—For ionising the wall of the rectum for ulceration and inflammation different methods are used. One method is to insert a zinc rod, six inches long, and covered by four layers of lint soaked in zinc sulphate solution (Wallace and Ironside Bruce). In another method a special electrode devised by Herschell may be employed. It consists of a copper or zinc wire bent to the form of a close spiral, enclosed in a rubber tube closed at one end, with a side opening near this end. The rubber tube with the enclosed spiral is contained in a larger membrane bag, which is wrapped closely round it. The whole is introduced into the rectum, with only the end projecting. Zinc sulphate solution can be made to flow, by gravity, slowly into the rubber tube from a douche can sufficiently elevated. It passes through the perforation and unwraps and distends the membrane bag into contact with the walls of the rectum. The metal spiral is connected to the positive pole of the source of current. Zinc ions migrate through the membrane into the rectal wall.

The mucous membrane of the colon may be ionised, in cases of colitis. Curtis Webb has described a method. An electrode made of a wire spiral, twelve inches long, enclosed in a rubber tube closed at the distal end and provided with a side opening near this end, is inserted as high up the colon as possible through the anus. Two indifferent electrodes are used; one is placed on the front of the abdomen, the other on the lumbar region. They are connected to the negative pole of the source of current. From a douche can a hot solution of zinc sulphate (2%) is gradually run through the rubber tube containing the spiral. It slowly fills the rectum and colon. The current is switched on and gradually increased till it reaches 15-20 milliamperes. It is allowed to flow for ten to fifteen minutes and then gradually lessened till it reaches zero. While the current flows, more of the solution should be allowed to flow in, so long as the patient tolerates it. The wire spiral is connected to the positive pole of the source of current.

In all cases where the interior of the bowel or other cavity is to be ionised, it is advisable to wash it out beforehand with warm water (distilled, if silver nitrate is to be used afterwards), so as to remove substances which might combine (like pus, for example) with the solution afterwards introduced; the lavage further clears away any substance in contact with the wall of the cavity.

Vagina.—To ionise the walls of the vagina, the latter is filled with a solution containing the ions. The current is conducted to this solution by a special metal electrode. The indifferent electrode is placed on the chest. The current then can traverse the vaginal walls and so cause the migration of ions into the latter.

Dr. Sloan, of Glasgow, has devised a method of conducting the operation and he uses special electrodes for the purpose. The operation requires practice and care. For full practical details the reader is referred to Dr. Sloan's recent work on the subject.* A brief outline taken from this work will be given here. A funnel-shaped electrode, made of vulcanite, is placed in position so that the narrow end lies, for a short distance, in the vagina, and the broad end rests against the vulva. Two metal tubes pass along the interior of the funnel but do not pass beyond the narrow end. One is for the inlet of the solution, the other for the outlet. The solution is run in from a reservoir by way of the inlet pipe, and it fills and distends the vagina, where it is maintained at a slight pressure. The funnel is kept in apposition against the orifice of the vagina by a spring support so that there is no leakage of fluid. The current is conveyed to the fluid in the vagina by means of a cable connected to the inlet pipe. Its strength should be from 20 to 50 milliamperes, and it should flow for 15 to 20 minutes. The patient lies horizontally on her back with the thighs raised (Fig. 36).

If the funnel is made of copper or zinc the vulva may be ionised at the same time. In this case the funnel does not rest in direct contact with the vulva but is

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* *Electrotherapy in Gynæcology.* By Samuel Sloan. Published by William Heinemann.

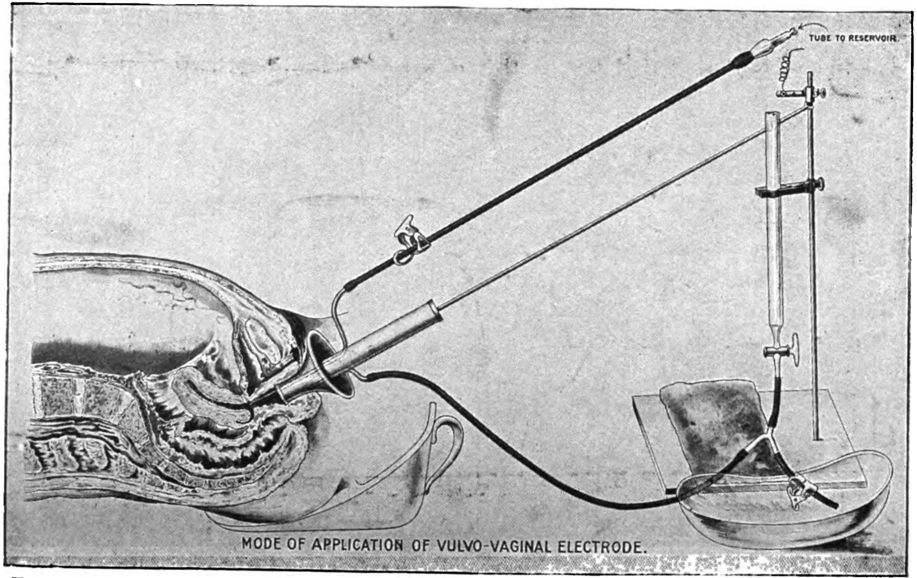

FIG. 36.— Mode of Application of Electrode for Ionisation of Vulva and Vagina (from Dr. Sloan's *Electrotherapy in Gynæcology*).

separated from it by ten layers of lint soaked in a solution of chloride of copper or zinc. The lint pad is cut to a circular or oval shape and the centre is perforated with a small circular aperture. It is placed against the vulva, and the narrow end of the metal funnel is passed through the opening so that this end rests in the vagina, while the broad end presses the pad against the vulva. The narrow end is covered by a short length of rubber tube so that the metal does not make contact with the vaginal wall.

Cervix.—By the method described for ionisation of the vaginal walls, the vaginal portion of the cervix is also ionised. If it is desired to confine the ionisation to this part of the cervix the following method is advised by Dr. Sloan. A glass speculum with its wall perforated at one end is passed into the vagina. The speculum is partly filled with the solution. A small metal spiral is placed in the speculum so that its end just dips into the solution. It is connected to the source of current.

To ionise the canal of the cervix, the glass speculum is passed. A copper or zinc metal rod is now passed through the speculum into the canal of the cervix. It is connected to the battery and a current of 15 to 20 milliamperes passed for 15 or 20 minutes. If the external os is gaping, or if there is erosion of the cervix, a special electrode should be used. It is a copper or zinc rod with a conical end shaped so that the free end passes into the canal of the cervix and the broad end rests against the part around the os.

If some solution of zinc or copper sulphate is introduced through the speculum so as to cover the cervix, it will pass through the side openings of the speculum and make contact with the vaginal wall at its upper end. If the metal rod is now passed into the canal of the cervix and the current started, ions will migrate into all parts with which the metal and the solution make contact. In this way, the canal of the cervix, the vaginal portion of the cervix, and the upper vaginal wall can be ionised at the same time.

Canal of Uterus.—An intra-uterine electrode is introduced into the uterus through the glass speculum. The patient is in the dorsal position. The electrode is secured to the speculum by means of a clip and its outer end is attached to a long handle which rests on the couch and serves as a support. A current, gradually increasing in strength, is passed till it reaches 15 to 20 milliamperes. If pain is produced the current should be reduced, and, if it does not cease when the current is reduced to zero, the case must be considered as unsuitable, for the time, for ionisation. Before the operation the vagina must be thoroughly douched and all septic discharge that is not washed away must be removed by a cotton-covered probe.

When there is difficulty in introducing the electrode with the patient lying in the dorsal position, she should lie in the left lateral position and the electrode inserted in the same way as a uterine sound. The electrode should be covered by rubber where it is not enclosed by the uterus, otherwise the current will pass into the vaginal wall wherever the electrode makes contact with it. After the current has passed for the appropriate time, the metal electrode will be found to have become adherent to the muesus membrane. The current, after reduction to zero, should be allowed to flow for a few minuts in the opposite direction. The electrode can then be removed without difficulty.

Duration of Ionic Treatment.—The duration of each session of treatment will vary according to the case, and definite times cannot be given. If a very slight thickness of tissue is to be ionised, as in the case of a corneal ulcer, the session need not last longer than a minute and a half or two minutes. For ulcers of the skin and mucous membranes the current should flow for 10 to 15 minutes. For inflammation of these parts without ulceration, treatment for 20 minutes should be given. If the skin and superficial fascia are quite thin the current should flow for at least half an hour if the operator wishes to introduce ions into parts lying immediately under the deep fascia.

The interval between two successive sessions of treatment—when more than one is necessary—also depends upon the case. When ions like zinc, copper, etc., that have caustic properties are used for treatment of ulcers and it is desired to produce some cauterisation (as, for example, in the treatment of rodent ulcer) the treatment should not be repeated until a week or ten days have elapsed. When ions that have no caustic action are used and the part to be treated lies under the skin, the sessions may be more frequently held, even every other day. If the erythema and slight degree of tenderness that follows each session have subsided, the treatment may be repeated.

The foregoing is a brief account of the principles of ionic medication, and the way in which it may be conducted. In Chapter XIV., in which the most suitable electrical treatment for different diseases and morbid conditions is set forth, reference will be found to those for which ionisation is the method recommended.

CHAPTER VI

SURGICAL IONISATION—THE USE OF THE ELECTRICAL CURRENT FOR DESTRUCTION OF TISSUE

Principle of the Method.—It has already been shown that new ions make their appearance at the points where the current leaves the anode to enter the electrolyte, and where it leaves the electrolyte to reach the kathode. Hydrogen ions are formed at the anode (if the latter is made of platinum) and hydroxyl ions (OH) at the kathode. In addition, there is some free undissociated hydrochloric acid at the anode and caustic soda at the kathode. These ions and molecules have a caustic action and, as they migrate and diffuse away from the electrode at which they are formed, precautions have to be taken, as described in Chapter V., to prevent them reaching the skin. When, however, it is wished to make use of their caustic properties for the destruction of tissue, special arrangements can be made for the purpose. The details differ according to the tissue that is to be treated, but the principle of the method is as follows. The electrodes consist of metal only. They are made of very small size and take the form of needles, so that, in the first place, the current will be very concentrated where it enters or leaves the tissue, and the number of ions formed at these points will be sufficiently large to produce caustic effects. In the second place, the needles are inserted into the tissue, so that the caustic action can be localised to the situation desired. If the needles are made of platinum the ions liberated will be hydrogen at the anode, and hydroxyl at the kathode. If the needle forming the anode is made of zinc or copper, then zinc ions or copper ions (not hydrogen ions) will be found at the anode; being present in concentration around the needle, they will extert a caustic action.

In performing surgical ionisation we may use one active electrode and an indifferent electrode; the latter is of the same kind as that described in the last chapter (Fig. 35). The active electrode may consist of a group of needles, instead of a single needle, and all are connected to the same pole of the source of current. The indifferent electrode can be replaced by a needle or group of needles which are connected to the opposite pole, so that all the electrodes are active.

The destruction of tissue by the ions liberated by the electric current is sometimes spoken of as electrolysis, and the action of the current as electrolytic. The electrolytic action is really a chemical action of the ions liberated by the current. With regard to the method, its great advantage lies in the fact that only so much of the caustic as is wanted is produced, and the caustic is made in the area where its effects are desired. The action is thus exactly localised and under perfect control.

It has been employed for the removal of superfluous hairs, warts, moles, for the destruction of nævi, strictures and caucerous growths, for the treatment of fibromyoma of uterus, and to produce coagulation in an aneurysmal sac.

The cases for which surgical ionisation is a suitable method of treatment will now be mentioned together with the method that may be adopted for each.

Removal of Superfluous Hairs.—For this purpose the caustic ions and molecules forming round the kathode are used to destroy the hair follicle. A good light is essential. On account of the uncertainty of daylight the author uses a metal filament electric lamp mounted and enclosed in a metal case which can move on a joint so that a beam of light can be directed on to the part requiring epilation. The opening of the follicle is most distinctly seen when the rays of light fall on the skin in a direction parallel to the hair at its exit from the follicle. An alternative but less effective method of illuminating the openings of the follicles is to suspend the lamp so that it hangs over the part requiring epilation, about 1 foot above. The lamp should be enclosed in a conical hood with nearly parallel sides so as to direct the light on to the skin and keep it away from the operator's eyes. A hood may be constructed from white card. The eyes of the patient should be closed or covered with an opaque cloth. On the patient's thigh is placed a mackintosh cloth and on this a flat electrode, moistened with saline, on which she can place her hand.

The current can be derived from the main, using a shunt resistence, or from a battery of cells. The regulator of the current should be within easy reach of the operator. One cable is fixed to the indifferent electrode and attached to the positive pole of the source of current. The other cable is attached to the negative pole and to the active electrode. The active electrode consists of a needle attached to a suitable holder (Fig. 37). The needle should be made of platinum-iridium alloy, three-quarters of an inch long, the terminal quarter inch bent at an angle of about 150°. This end should be no thicker than 0·2 mm. The rest of the needle should be stouter, say 0·4 mm. This end is inserted into the holder,

FIG. 37.—Epilation Needle fixed to Holder.

The free end of the needle must be rounded, not pointed. Platinum needles are not sufficiently rigid when bent at an angle. Pointed needles are more likely to make false passages when attempting to pass them into the hair follicles. Steel needles should not be used, as they will leave an indelible black stain if they are accidently connected to the positive pole. Steel, also, corrodes quickly, unlike platinum and iridium.

To perform the operation, the needle should be inserted into the follicle, following the direction of the hair. It passes one-eight or one-sixth of an inch before its tip reaches the bottom of the follicle. The patient then places her hand on the indifferent electrode and the operator increases the current from zero to 2 milliamperes. Effervescence is seen at the mouth of the follicle. The current is allowed to flow for 15 seconds, and then the needle is withdrawn. The hair is then seized by an epilation forceps and withdrawn. It should come away without the slightest effort. If it does not come away readily the needle should again be inserted. The position of the current regulator is not altered, but kept at the same position so that 2 milliamperes of current are supplied. For each of the remaining hairs the patient lifts her hand off the electrode, the operator inserts the needle, the patient replaces her hand, and the hair is taken out of the follicle after 15 seconds flow of the current. If the milliamperemeter needle indicates that the current is increasing beyond 2 milliamperes, the strength should be reduced to the value mentioned. Larger currents will destroy more tissue and cause more pain. Smaller currents may not sufficiently destroy the follicle.

There is a sharp stinging pain at the moment the needle is in the follicle, but it is not so severe that an anæsthetic is necessary. The local application of cocaine is useless unless introduced by the ionic method; even then it is not advisable.

When a large number are to be removed, only from twenty to thirty should be done at a single sitting, and these should be removed from over the whole surface. If this number were removed from one spot a troublesome ulcer might result and leave a scar. The successful use of this method requires both practice and skill. Hypermetropia and astigmatism greatly hamper the operator and, if marked, prevent successful epilation. Myopia, on the other hand, is an advantage. A very useful aid to those with defective eyesight is a pair of spectacles with a strongly convex lens fitted to one side only. A lens fitted to the needle-holder hampers rather than helps. Under the best conditions a certain number of the hairs (about 20%) return and have to be removed again. For the removal of fine hairs a finer needle, a weaker current and greater skill are required. Fine downy hairs cannot well be removed by electrolysis. If they lie very closely together and electrolysis be attempted, scarring will be caused.

Some operators derive help by holding the hair in a forceps while passing the needle into the follicle. It is very important to pass the needle in the right direction, as it may easily make a false passage and pass out of the follicle after insertion through the mouth of the latter. When this happens, the needle passes easily down to its bend, and is not stopped by the base of the follicle.

Nævi.—Surgical ionisation is a valuable method of treatment of certain nævi. It is specially indicated for venous nævi (cavernous angiomata) because the overlying skin is saved, and the scarring is reduced to a minimum. If the skin contains capillary nævus, some scarring is unavoidable. Surgical ionisation is also indicated for nævi composed of vessels distinctly separated from each other, for stellate veins (spider nævi), for teliangectases in adults and for very minute capillary nævi. Excision, or freezing with CO_2 snow is quicker for large capillary nævi. The galvano-thermo-cautery may also be used for these. Surgical ionisation is also effective for nævi which are raised like moles (nævus verrucosus). The object of the treatment is to break up the blood vessels and coagulate the blood therein without causing general necrosis and sloughing. The destruction of the vessels and coagulation of the blood is caused by the caustic ions formed around the electrodes. If the growth is subcutaneous, the skin will not be injured, if the operation is carefully performed. If the skin is also involved, a certain amount of scarring is unavoidable. Minute scars are left on the spot where the needle electrodes punctures the skin.

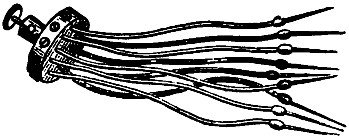

FIG. 38.—Needles for Electrolysis.

There are two chief methods of destroying nævi by the ionic method—the unipolar and bipolar method. In the bipolar method both electrodes are active. In the unipolar method there is one active and one indifferent electrode.

The Unipolar Method.—This method is preferable when the nævus is composed of vessels that are visibly distinct and separate from each other. The active electrode consists of a needle, fixed to a holder, or a group of needles (Fig. 38). The needles may be made of zinc. The indifferent electrode should be a felt-covered metal plate like those used for ionisation. It is connected to the positive pole.

To perform the operation, a general anæsthetic will be required for children. The indifferent electrode is securely attached to the trunk or leg. The needle or needles are then inserted into the skin so as to transfix the vessels. Two to four milliamperes will be required for each needle, and the current is allowed to flow till the vessels are obliterated at the points of insertion. When the nævus is situated on the face or head, the current, in its passage through head and neck to reach the indifferent electrode, may cause shock and faintness and irregular breathing, especially in children. It is, therefore, safer to dispense with the indifferent electrode and use another active electrode, and insert it into another vessel. This electrode may also be a zinc needle. The method described may also be used for minute capillary nævi. For larger capillary nævi this method takes considerable time.

Stellate veins are treated in the following way. A zinc needle, attached to a suitable holder, is passed for a short distance, say about one-eight of an inch, into the central vein from which the others radiate. The needle is connected to the positive pole and the circuit is completed by placing the indifferent electrode on some other part of the body. A current of 1 milliampere is passed for one minute. The central vein is coagulated by the zinc ions and the radiating vessels disappear. A minute scab forms, but drops off in a few days, and leaves a minute scar, which afterwards becomes almost invisible.

The Bipolar Method.—This is to be used for caverous nævi and is best performed by means of a bipolar needle electrode devised by Dr. Lewis Jones and shown in Fig. 39.

The two wires from a battery are joined to the two terminals shown. The internal connections are such that the needles are joined to the positive and negative poles alternately. Two, three, four, or five needles may be used, according to the size of the mass to be treated. The needles are pushed through the mass. A milliamperemeter must be in circuit and the current not allowed to exceed 20 milliamperes for each inch of positive needle inserted. The needles should be made of an alloy of platinum and iridium and sterilised by heating to redness before use. The needles should be inserted parallel with the surface. After the current has passed for a quarter of a minute they should be partially withdrawn and pushed in again in a different direction. The process should be repeated several times, so that the needles explore all parts of the nævus and break up its blood vessels. While this is being done watch is kept on the skin where the needles have pierced it, so as to avoid the risk of destroying it. Soon after the needles are inserted the following changes take place in the tissue in contact with the needles. Round the positive needles there is hardening and pallor and the needle tends to become fixed and difficult to withdraw. Round the negative needles there is frothing with the hydrogen gas produced, while the needle itself gets very loose. The nævus gradually loses its consistency; it swells and acquires a firmer consistency so that gentle pressure with the finger-tip does not empty it. At this stage the blood has been coagulated and the operation is now complete. In using this electrode, Dr. Lewis Jones considered the current should not exceed 20 milliamperes per inch of *positive* needle, if sloughing is to be avoided. The pain is severe, and an anæsthetic is required

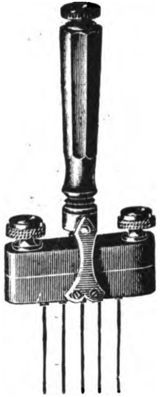

FIG. 39. — Bipolar Needle Electrode.

in practically every case. For after-treatment a piece of antiseptic gauze is applied over the punctures with flexible collodion. If sloughing supervenes an antiseptic poultice is applied at first until the slough is cast off and the ulcer treated on general principles. Small nævi, not over one-quarter of an inch in diameter, can be destroyed at a single sitting. When larger than this, two or more sittings may be necessary.

As the tendency of most nævi is to increase in size, they should be treated at the earliest possible time, and special attention should be given to the margin in all cases if recurrence is to be avoided.

The treatment of extensive port-wine marks by surgical ionisaton is a very slow process as the area treated at each sitting is very small. Zinc needles are inserted into the nævus vertically and a current of 3 milliamperes used for each needle. A quicker method of treatment is by high-frequency or diathermy sparks.

Warts.—These are treated in the way described for stellate veins. The zinc needle is made to transfix the base of the wart at the level of the skin. A current of 1 milliampere for one minute is sufficient. If the wart is larger than about one-eighth inch in diameter it may be transfixed again, once or more, in different directions, and the same strength of current applied and for the same time.

This treatment is very successful. The wart gradually shrivels and drops off in a week or ten days.

The method described is sometimes called "zinc needling."

Moles.—Hairy moles are best treated by removing the hairs in the way prevously described. Much of the mole will disappear when the hairs are removed. Moles that are not hairy can be removed in the way described for warts. They usually require to be transfixed in several directions.

Strictures of Urethra.—Very little has been heard of the electrolytic treatment of strictures during recent years. It offers no very decided advantages, and if sufficiently strong currents are used to produce active destruction of the scar tissue at the stricture, it is attended by some danger. A large indifferent electrode is placed on any convenient part of the patient's body, and is connected to the positive pole. The active electrode consists of a flexible metal stem, terminating in a bulbous enlargement. The latter is left bare, and the stem is covered with insulating material. One is shown in Fig. 40.

At the proximal end is provided a terminal for attaching it to the negative pole. The size of the largest bougie that will pass the stricture, as well as the distance of the latter from the meatus, having been ascertained, a bougie electrode is selected two sizes larger, and a mark made on its shank corresponding to the distance of the stricture from the meatus. It is now passed down to the stricture against which it is held, but no force is to be used under any circumstances. The circuit is closed and the current gradually increased until 5 or 6 milliamperes are passing. The pressure on the bougie must be gentle, and in the direction of the urethra, otherwise a false passage may be made. The pressure is kept up until the bougie passes through the obstruction and into the bladder, when the current is to be at once gradually reduced to zero and the instrument removed.

This operation may have to be repeated at intervals of not less than three weeks.

Another method is that of "linear electrolysis." The active electrode consists of a long, flexible bougie, in the middle of which is a projecting blade of platinum (not sharp). This blade is connected to a terminal at the outer end. The leading end is filiform and serves as a guide. The instrument is introduced, and the blade pressed against the stricture. The current is gradually increased until 10 milliamperes are passing, which is sufficient in most cases.

The method is one which might be termed "electrolytic incision." The instrument is pressed against the stricture until the latter is divided, which takes place in about thirty seconds. Strictures in other parts, such as the lachrymal duct, Eustachian tube, œsophagus, and rectum, have been treated by electrolysis. The method differs in no essential particular from those given for stricture of the urethra.

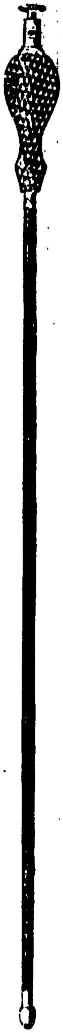

FIG. 40.

Uterine Fibromyomata.—A great deal has been written for and against this treatment of uterine "fibroids" since Apostoli published his method in 1882.

The action is to destroy the uterine mucous membrane: this results in a reduction of the size of the uterus and a decrease of the hæmorrhage. The most that can be gained in the great majority of cases is a temporary relief of symptoms.

Apostoli used an internal positive electrode of platinum, and an indifferent electrode of moist china clay, and a current of from 50 to 80 milliamperes passed for from five to fifteen minutes. The method is not much employed now.

Aneurysm.—The treatment of this condition by electrolysis has not been satisfactory. The best results in this country have been obtained by the late Dr. John Duncan, of Edinburgh. It is only applicable in cases where ligature is impossible or attended by special risks. The great objection to the method is the necessity of piercing the wall of the sac with the risk of setting up hæmorrhage. The needles must be insulated except at the points, so that no bare metal comes in contact with the sac during the passage of the current. Both positive and negative needles are introduced into the tumour, and large currents and long sittings are necessary.

Malignant Growths.—In the hands of some workers good results have been obtained in the treatment of carcinoma and sarcoma. The method which appears to have been most successful consists in plunging into the cancerous mass one or more small rods of amalgamated zinc—a puncture being first made with a scalpel to permit of the insertion of the rod or rods. These are connected to the positive pole of the battery—a large indifferent electrode being arranged under the patient. A general anæsthetic is always necessary. Large currents and long sittings are the rule. The method is an application of the ions of zinc and mercury in sufficient concentration to produce caustic action. Complete destruction of the growth takes place in the immediate vicinity of the anodes and atrophy in the area farther away. It is largely practised by Dr. Betton Massey, of New

York, who claims that he has had very good and encouraging results in a large number of cases of inoperable malignant disease. The method has not been used to any great extent in this country, but it ought to be given a further trial. It does not prevent the occurrence of metastases.

CHAPTER VII

IONISATION IN DEEP-LYING TISSUES

In the methods of treatment described in the two preceding chapters the constant current has been used for definite purposes; first, to take into the diseased part the ions of the drugs of which the therapeutic action is known; secondly, to deposit the ions of caustic chemicals where desired, in order to destroy tissue.

The constant current is known also to produce therapeutic effects in general or local maladies in which its *modus operandi* is less evident. The effects are not due to the ions that are taken in from without, because these ions may have no therapeutic value. Thus the electrodes may be soaked in salt solution; under these circumstances sodium ions enter at the positive electrode and chlorine ions at the negative electrode. It is unlikely that the good results that follow the application of the constant current to a sprained joint, for example, are due to the entry of sodium ions from the positive electrode and chlorine ions from the negative electrode. Even if the ions of drugs known to be of value in the treatment of disease are contained in the electrodes, they are not likely to migrate more deeply than a few millimeters in the time during which the current is usually allowed to flow during a session of treatment. It is therefore necessary to seek some other explanation. The question must nevertheless be considered from the point of view of the behaviour of the ions. The constant current causes a steady movement of the ions *normally present within the tissues,* either in the same direction as the current or in the opposite direction, according to the charge carried by the ion. There must therefore be some redistribution of the tissue ions. It cannot be said whether such redistribution has any therapeutic effect, but it is possible that there are ions of disease products in some morbid conditions, and if such is the case the constant current would cause their migration out of the tissue and into the vessels. A mode of action of this kind was suggested in Chapter I. to explain the disappearance of fatigue from tired muscles, following the application of the constant current.

The migration of the ions acts as a stimulus, at any rate to some of the tissues, as, for example, the sensory nerves. The steady flow of the current through the skin causes a burning sensation as the ions pass through the sensory nerves.

The erythema that is evident in the skin after the current has been passing through it shows that vaso-dilatation is produced. It is likely that there is some vaso-dilatation in the deeper parts also and possibly some stimulation of the tissues in the same region. In those maladies where the passage of the constant current produces cure or relief, the tissue stimulation and vaso-dilatation may be contributing factors. The passage of the constant current through a fluid effusion, such as is found in a joint after injury, is often followed by disappearance of the effusion. It is possible that this disappearance may be due to migration of ions from it and lowering of its osmotic pressure. The power of the galvanic current to relieve pain due to disease in deep parts, e.g. neuritis of the sciatic nerve, may be due to some action of the current on the peripheral sensory nerve endings in the skin. Application of friction or heat to the skin, cupping, etc., frequently produce relief and it is possible that the migration of ions into the endings of the sensory nerves supplying the area of skin to which the pain is referred, act in the same way as the mechanical and thermal stimuli applied to the skin. The ions of drugs may be more effective than those of inert chemicals such as sodium chloride. Leduc has shown that the excitability of peripheral nerves is profoundly modified in different ways by the different ions.

It has been mentioned, in Chapter I, that there is a diminution of excitability and conductivity (anelectrotonus) in the region of the entry of the galvanic current. Although pure anelectrotonus cannot be obtained, as shown on page 88, it may be produced in excess of katelectrotonus, especially in the sensory nerve-endings in the skin, and contribute towards producing relief of pain.

To apply the current for treatment of diseases of the deep parts, electrodes like those described in Chapter V. for medical ionisation may be used—viz. absorbent pads for placing in contact with the skin and felt-covered metal plates for attachment to the cords leading from the source of current. They must, of course, be soaked in a solution of an electrolyte, so that they may conduct the current. Sodium chloride is used. If it is wished to introduce some special ion, as well as to influence the deep parts, the pad is soaked in a solution containing the ion and connected to the correct pole. If sodium chloride is used, sodium ions will migrate inwards from the pad connected to the positive pole, chlorine ions from that connected to the negative pole. It is important that the electrodes should be of sufficient size so as to overlie the whole of the part requiring treatment. With small electrodes the maximum current density that the skin can tolerate is reached with a small current, and when this small current has spread along divergent paths in the deep parts the amount of current in any one part is very small.

For application of the current to the *abdomen*, so as to treat the alimentary canal, an electrode that covers the whole of the anterior surface should be used, while another of the same size should be placed on the back.

For application to the *brain*, one electrode (the kathode) is placed so as to cover the forehead, the other is placed on the back of the neck.

For the *spinal cord* an electrode three inches wide and of a length equal to that of the part to be treated is placed over the vertebral column. This electrode is usually the kathode. The anode may be placed on the front of the chest, its total area of contact with the skin being not less than that of the kathode.

For application to the *shoulder joint*, one electrode should be placed on the anterior aspect of the shoulder, the other on the posterior aspect. If one electrode is placed so as to surround the shoulder (the other being placed on the forearm) much of the current will pass through the muscles around the joint and through the parts in the axilla, and less will pass through the joint. If the current is directed from arm to arm, only a small portion, probably, will pass through the shoulder joints.

The *hip joint* is closest to the surface anteriorly. One electrode should be placed over the groin. The other may be placed on the buttock. The patient should be recumbent and lie on the latter electrode.

If both legs are immersed in the Schnee bath and no electrode placed over the joint, only a small portion of the current will traverse the hip joints, because the latter are surrounded by better conducting tissues.

There is more likelihood of the current traversing a joint throughout, if the electrodes are placed on opposite aspects, both antero-posterioly and when possible, laterally, on separate occasions or successively. The electrodes should be, as far as possible, equi-distant. If their edges approach too closely, the current will be more concentrated in the region of the closely opposed edges.

Among the morbid conditions for which the application of the constant current produces good results may be mentioned *congestion,* with or without effusion, particularly when the exciting cause (*e.g.* trauma) has ceased to act. Chilblains can usually be cured by the galvanic current, and the frequency and severity of the attacks in Raynaud's disease are often reduced. The methods of application are described in Chapter XIV. The current aids the absorption of inflammatory products when the cause, responsible for their appearance, has disappeared. The best results are seen in bruises, sprains, fractures, and dislocations. Pain due to neuritis is often relieved. Gouty and gonococcal arthritis are often benefited. The Rheumatoid arthritis and osteo-arthritis are occasionally relieved temporarily, but this is the exception rather than the rule. Some cases of progressive muscular atrophy are benefited by application of the constant current to the spine. The same treatment often relieves the crises and pains of tabes dorsalis, and it is of value in some cases of neurasthenia and hysteria. Leduc recommends its application to the brain in cases of cerebral fatigue and exhaustion.

The diseases for which the application of the constant current, "galvanisation" as it is often called, is suitable, will be found in Chapter XIV. In these cases the current is not applied for the purpose of introducing new ions from without.

CHAPTER VIII

THE USE OF THE ELECTRICAL CURRENT FOR THE STIMULATION OF THE TISSUES—ELECTRIC BATHS

Currents which do not flow continuously in the same direction, but periodically reverse, are unable to cause the migration of ions. They nevertheless possess valuable therapeutic properties. Diseases in which there is an impairment of vitality, weakness or loss of power of the muscles, maladies such as anæmia, rickets, gout, etc., can be markedly benefited by alternating and intermittent currents. It is now necessary to consider the mode of therapeutic action of such currents. It is not easy to state the precise way in which such stimulation brings about the cure or relief of disease, but there is abundant clinical evidence of the fact.

Tissues Stimulated by the Electrical Current.—In the case of animals under physiological experiment, all the excitable tissues—muscles—striated and non-striated; nerve fibres, medullated and non-medullated; and nerve cells—can be stimulated, and ocular demonstration can be given in most cases. In the human subject, however, the conditions are different. The skin screens the tissues and organs from direct observation, and the stimulating electrodes cannot be placed in direct contact with the part to be stimulated. It is, therefore, impossible to get actual proof, except in a few instances, that all the excitable tissues traversed by the current are stimulated. Muscles, however, can be observed to contract, in response to stimulation of motor nerves. Sensory nerve endings can be stimulated as shown by the subjective sensation of pain, prickling, etc. Impulses are thereby conveyed to the central nervous system and reflex effects may be produced. One example is the rise of arterial blood pressure following stimulation of the skin. The rise is due probably to constriction of the arterioles.

There is no reason to suppose that the tissues lying deeply are not stimulated, although, by reason of their position at a greater distance from the electrodes, they receive a smaller portion of the current. Even a subminimal stimulus, a stimulus insufficient to produce the customary physiological response of the part excited, may have a beneficial therapeutic effect. D'Arsonval showed that the production of muscular contractions by the faradic current augmented the respiratory exchanges, but if the current was insufficient to cause any muscular contraction, augmentation of the respiratory exchanges was nevertheless observed. He showed that sinusoidal alternating currents produced a greater increase than the faradic, and that the constant current did not affect the respiratory exchange.

We may now consider the different kinds of alternating and intermittent currents and their suitability for the stimulation of various tissues.

Currents used for Stimulation of Tissues: (1) *The Faradic Current.*—This has been described on p. 31 *et seq.* The current is alternating and intermittent, and the alternations are frequent, the rate depending on the virbrating hammer. In a *suitably designed* coil the current at "make" is imperceptibly small; that at "break" (the stimulating current) flows for an extremely brief duration ($\frac{1}{1000}$ sec.). Impulses of this brevity will stimulate motor nerve, not those which convey the sensation of pain; consequently, the faradic current is useful for the purpose of causing painless contraction of muscles in the treatment of some forms of paralysis.

(2) *The Sinusoidal Alternating Current.*—This is described on p. 26. When the periodicity of this current is 100 *i.e.* 100 complete phases per second, the current flows for 1/200 sec. in each direction before reversal. Impulses of this duration are long enough to stimulate sensory nerves as well as motor nerves. The sinusoidal alternating current is the most useful current for general stimulation of the tissues and is very suitable for application in baths. It seems to stimulate sensory nerve more strongly than the faradic current.

The periodicity of alternating currents supplied on the main is lower in some districts than in others, but is is never lower than 25. When the periodicity is 25 the current flows for 1/50 sec. in each direction before reversal. Currents of still lower periodicity are called slow sinusoidal currents. They are believed to be more effective stimulants of involuntary muscle than quick sinusoidal currents. Currents with a periodicity of 1·7 are sometimes used for the treatment of atony of the stomach and intestine. Such a current flows for 0·3 sec. in each direction before reversal.

(3) *The Simple Interrupted Current.*—This is described on page 19. It is used for the stimulation of voluntary muscle, of which the motor nerve has been paralysed and lost its excitability. It is used also in testing the electrical reactions of muscles and nerve (to be described later).

(4) *The Simple Alternating Current.*—This is described on page 24. It is used for the treatment of paralysis of voluntary muscle, when the reactions of

the latter are abnormal, some workers preferring it to the simple intermittent current.

It may be found, in the future, after more work has been done on measurement of electric stimuli, that each excitable tissue has its own most effective stimulus, in the matter of strength, duration, rate of rise to maximum and fall to zero, and frequency of repetition. Leduc has shown by means of his special interrupter (described on p. 21) that the most effective stimulus for motor nerve and voluntary muscle is the simple intermittent current, interrupted 100 times per second, flowing for periods of 1/1000 sec., each period of flow followed by a period of rest lasting 9/1000 sec.

Until, however, similar work has been conducted on other tissues we must use the "ready-made" currents already described, and rely on clinical evidence to guide us in the selection of the most useful currents for the treatment of disease. The quick sinusoidal alternating current is probably the most useful at present.

Rhythmic Interrupters.—Currents of which the interruptions and reversals are frequent should not be applied to the body with their strength unvaried. If this is done, the muscles will be tetanised, and prolonged contraction injures them. The current, whatever its modification may be, should be made to slowly wax and wane, gradually rising from zero to maximum and gradually falling from maximum to zero. The muscles will then relax between the contractions and their blood supply will be periodically replenished.

The other tissues will also be more effectively stimulated if the current is made to increase and diminish slowly and periodically. This may be brought about by including in the circuit a resistance that is continually varying. Such a varying resistance is shown in Fig. 41. It consists of a cylindrical or conical glass vessel filled with tap-water. A vertical metal rod that leads the current into the water is made to rise and fall (by means of clockwork or a small motor) within the water in the cylinder and so interpose a column of water of varying length between the free end of the rod and the bottom of the cylinder through which the current leaves the vessel. Tap-water has a high resistance, so that when the wire is high up in the cylinder a

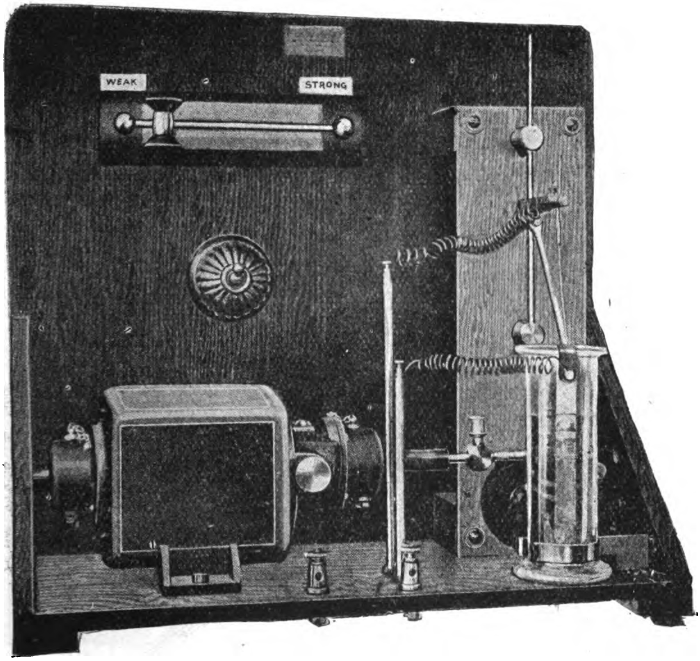

FIG. 41.—Rhythmic Resistance-varying Device, Motor-driven.

greater length of water is interposed for the passage of the current. The current in the rest of the circuit is very weak, or stopped altogether. As the wire descends, so the current becomes stronger, and when the wire reaches the bottom of the cylinder the current is at its maximum strength. The rate at which the current rises to its maximum and falls to zero can be varied, but usually the complete cycle (*i.e.*) the rise to maximum and fall to zero lasts from two to four seconds.

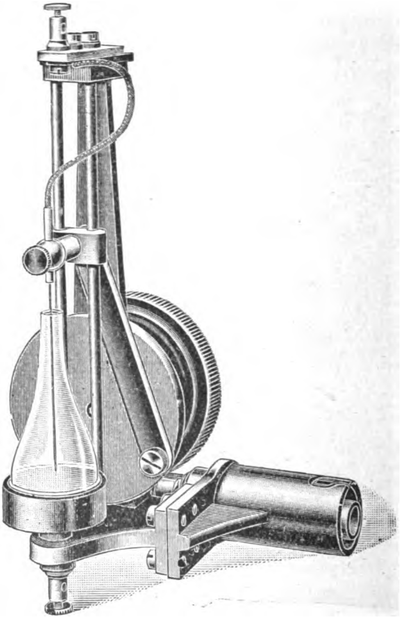

FIG. 42.

Current regulators working on this principle are very useful for electro-therapeutic work.

Another, working on the same principle, is shown in Fig. 42. This is made to fix on to the motor of the Pantostat, so that the revolution of the axle of the motor causes the slow rise and fall of the metal rod in the water. The sinusoidal and constant currents furnished by the Pantostat may thus be rhythmically varied in strength.

Tap-water should be used to fill the glass vessel. Distilled water (*i.e.* water containing nothing in solution) will conduct the current scarcely at all, and it should contain just a sufficient amount of salt dissolved, so that when the wire rises to its highest position in the solution there shall be sufficient resistance interposed to just prevent the passage of current. Average tap-water contains a sufficient quantity of salts in solution. If more salts are added its resistance will be made too low, the current will at no period be cut off altogether, and there will be insufficient range of variation between maximum and minimum. If this device is used to vary a *constant* current, it will be noticed that the resistance of the water gradually rises. It may be lowered by cautiously adding, a drop at a time, 10% salt solution.

If there is no instrument at hand for producing rhythmic variation, a certain degree can be effected by moving one of the electrodes that convey the current into the body, rhythmically over the skin, stroking the latter over the area that is to be treated, lifting it off at the end of each stroke.

Application to the Body.—When the treatment is applied locally, electrodes like those already described for ionic medication may be used. They should be of large size, sufficient to cover the whole part requiring treatment.

The strength of current that a patient can bear depends upon its density or concentration at the places where it enters and leaves the skin. If small electrodes are used, small ports of entry for the current are provided, the current becomes unduly concentrated in the skin, the sensory nerves are strongly stimulated, and much pain is produced, even though the underlying muscles are receiving little current.

A large surface for entry of the current ensures the maximum current for the parts under the skin, with the minimum concentration or density in the skin. In other words, strong applications may be given without discomfort or pain.

The electrodes are made of absorbent cloth, such as lint or folded towel, soaked in warm salt solution (2% is strong enough) and felt-padded metal plates, similarly soaked, are placed in contact with them. The metal plates are connected to conducting cords leading from the source of current.

If rhythmic variation is to be effected by moving one of the electrodes over the surface, this electrode cannot, of course, be of a size sufficient to cover the whole part requiring treatment. It should, however, be not less than one third of the area over which it is moved.

The importance of large electrodes and good contact between them and the skin has been emphasised on previous occasions. These requirements can be most easily fulfilled by using water as the electrode; the water is placed in a bath and the part to be treated is immersed in it. The application of electrical currents in baths has special advantages. The time occupied in fitting pads and removing them is saved. The part can be kept warm if hot water is used in the bath. Water acts as a perfectly fitting electrode of the largest possible size. The use of electrical baths will now be considered in more detail.

Electric Baths.—These are made of porcelain or earthenware, or of some other insulating material, such as wood or fibre. They are made of sizes and shapes to take a single extremity, such as the hand and forearm, or leg and foot. Or it may be a full-length bath to take the whole body. The current is led into the water in the bath by means of a plate of carbon or metal that hangs from the edge of the bath and dips into the water. The plate and the water thus correspond to the pad electrodes that have hitherto been used. Now, in order to complete the circuit, we require a second electrode. If we are using the arm baths or foot baths, one of these may be used as the indifferent electrode, with one of the extremities immersed in the water. This is known as the unipolar method of applying the current, because there is only the one pole in each bath. With this arrangement *all* the current that is flowing in the circuit passes through the skin of the part immersed, into the limb, through the body and out by way of the limb in the indifferent bath electrode. With this arrangement, therefore, other parts of the body share the treatment. Thus, if the forearm and hand are immersed in one bath, the leg and foot in another, the electrical treatment will be given to the hand and forearm, the upper arm and shoulder, trunk, hip, thigh, leg and foot. The skin of the parts that are not immersed will receive very little current, because the latter, having traversed it in the immersed parts, keeps to the underlying parts, as the resistance of the latter is low, and that of the skin high.

With the arrangement described, electrical treatment may be given to any two of the extremities simultaneously. The trunk does not receive much stimulation, as it is the widest part of the circuit, and so the current density is low.

If it be desired to treat the four extremities simultaneously, two more baths are provided, to take the other limbs. The current can be sent from any two to the remaining two, or from any one to one or more of the remaining three. When the four extremities are receiving treatment simultaneously the trunk receives more stimulation, so that the whole body (except the head) can receive electrical treatment by this arrangement.

The Schnee bath is an arrangement of four baths, one for each extremity. It is shown in Fig. 43. By its means the current may be applied to two or more of the extremities, the trunk sharing it to a greater or lesser extent. The Schnee bath is useful for applying the electrical current to the whole body. There is, however, no stimulation of the skin except that of the parts immersed. When the current is applied to the body by means of the Schnee bath there is less likelihood of stimulation of the sensory nerves than when the whole body is immersed. Under the skin the nerve trunks lie in better conducting tissues and more of the current travels in the latter. When the current enters the body through the skin the endings of the peripheral sensory nerves are stimulated in the epithelium and the adjacent papillæ. Reflex stimulation of various organs is therefore the more complete the larger the area of the skin immersed for the entry of the current.

A switch-board is supplied with the Schnee bath outfit, so that the current that is available can be directed between two, or more, of the baths, Either the faradic or the constant or the sinusoidal current may be used.

In the case of the full-length bath, both electrodes are immersed in the water, one at either end. The current passes between the electrodes and travels partly through the water, partly through the body.

The Full-length Bath.—As a means of applying electricity to te whole body the electric bath is the most agreeable and most efficient method we have.

Large electrodes are placed at the head and foot, and the bath is filled with water at a temperature of from 98° to 100° Fahr., so as to cover the patient's shoulders when he is in a semi-recumbent position.

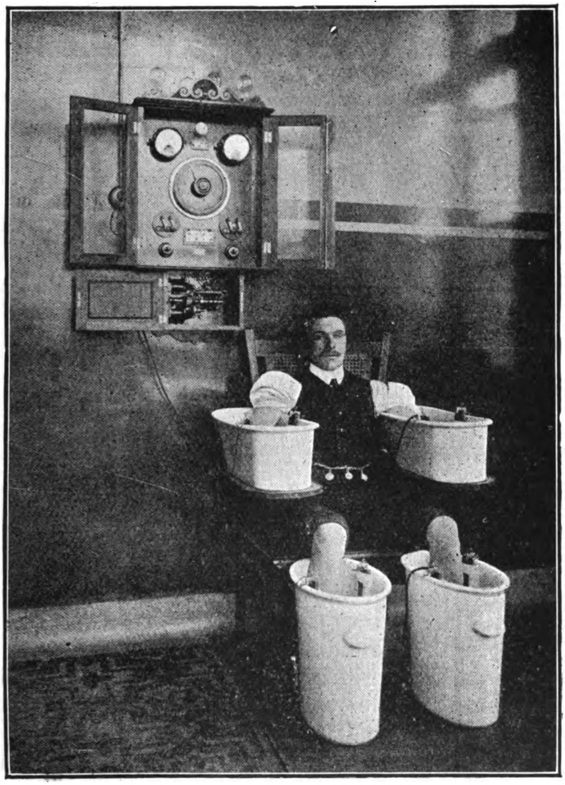

FIG. 43.—Schnee Bath.

The electrodes should be of metal and kept clean and bright. They should be 12″ x 18″ for the head end, and 12″ x 10″ for the foot end of th bath. A paddle electrode (Fig. 44) connected to one of the others is sometimes used by the operator to concentrate the current on any required part. It consists of a plate of metal, 4 inches square, mounted on the end of a long handle. It is connected to one of the other electrodes or it may replace it. A back rest, made of a wooden frame with strips of webbing stretched across, is required for the patient to lean against, and keep him from contact with the electrode. A similar one is not required for the foot. They should be made to fit the bath in which they are used or they will give trouble.

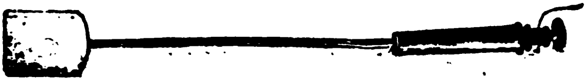

Fig. 44.—Paddle Electrode.

The full-length bath is a "bipolar" bath, as both electrodes are immersed in the water. The current will pass through the water from pole to pole, and some of it will pass through the body, the relative amounts depending on the resistance of the body and the resistance of the surrounding water. If there is much surrounding water, its resistance will be less than if there is a smaller quantity, and a greater share of the current will be taken by the water, leaving less for the patient. If salt were added to the water the resistance of the latter would be much lower and still less current would pass through to the patient. The amount of current passing through the patient is not the same in all parts of the body; the thick trunk has a smaller resistance than the narrower limbs, so that the former will take more of the current than the latter.

The full-length bath allows a greater general stimulation of the body than the Schnee bath, because in the latter only portions of the skin are immersed. By means of the full-length bath it is possible to administer the largest quantity of electricity to the body, because the current is provided with the largest possible area of entry.

Current for Use in the Bath.—For the purpose of general stimulation of the body a valuable current is the sinusoidal. It should be applied so that it slowly and rhythmically varies in strength as it passes through the patient. The current may be taken from the main, using a static transformer when the main current is *alternating,* or a motor generator when it is *direct.* If there is no main supply at hand, the current from a battery of accumulators may be taken to the motor generator. An alternative method is to use the faradic current, also rhythmically varied. The *direct* current from the main should never be sent directly through the bath, on account of the risks mentioned on page 64.

How the Electric Bath is Given.—The bath should be filled with warm water at 99° or 100°, as measured by a thermometer, to a height sufficient to cover the shoulders. The wire connections should be tested to see that they are not loose and then the current is turned on to half strength. The operator should place his hands in the water so as to be sure that the current is flowing. The current is then reduced to zero again. The patient then enters the bath, and the current is gradually increased, little by little, till no more can be borne without discomfort. After ten or twenty minutes the current should be gradually reduced to zero, as before.

If languor or depression follows the bath it may mean that the current has been too strong, but some degree of fatigue is customary after an electric bath. It is temporary, and the patient should be forewarned of its likelihood. The patient should dress slowly, so as to cool off gradually, and rest for a quarter of an hour or so before going out into the open air. There is no special liability to catch cold after an electric bath, particularly if the patient walks home, which he should always do if possible.

At least twelve baths are required to produce a satisfactory result—but many cases arise in which it is found necessary to give a great many more. In no form of electrical treatment is it more necessary to exercise the utmost care than in everything pertaining to the electric bath; what would be of more or less trivial account under other conditions becomes a serious matter here. Any sudden change in the magnitude of the current, however small, has a very alarming effect on the patient. This is not unreasonable, considering how helpless he is when immersed in the water, and so placed that small changes have as much effect as large ones under other circumstances. Binding screws, conducting cords and the slider of the regulating resistance are all sources of trouble. They should be frequently inspected and tested, and all the apparatus should be personally examined by the medical man before each bath is given. He should turn the current on himself and not leave the room until he has turned it off, before the patient comes out. For female patients a bathing dress is necessary, as is also the presence of a nurse or maid in the room. The electric bath is one of the most valuable methods of treatment for procuring stimulation of the whole body.

General Faradisation or Galvanisation.—In the absence of an electric bath there is another method of bringing the whole body under the influence of the electrical current.

The patient stands or sits on a large metal plate, which is covered with moist flannel, and if necessary kept warm by a hot-water bottle. One wire from the induction coil is attached to this plate, and the other to the active electrode. The latter may be a felt-covered metal plate with a handle attached for the operator. Sponge may be attached to the felt. It is moved over the head, neck, back, abdomen, arms and legs—from two or three minutes being given to each. The strength of current is not so great as to be the least unpleasant. A pleasant feeling of vigour follows, with relief of fatigue and improved appetite and ability to sleep. There is no doubt as to the great value of the method, and it is the one to employ whenever the electric bath is not available.

The faradic current may be used alone on in combination with the constant current. This combined treatment was suggested by De Watteville and the treatment was called by him " galvano-faradisation."

CHAPTER IX

ELECTRICAL TREATMENT OF PARALYSIS

ELECTRICITY is a valuable agent for the treatment of paralysis and will, in suitable cases, give results that cannot be obtained by other methods. It it, however, of the first importance that correct methods of application should be employed, and it is the failure to recognise and adopt them that is generally responsible for the inability to obtain good results, and for the scepticism that still prevails in some quarters regarding the value of the treatment.

In any case of paralysis we have to consider, for the purpose of electrical treatment, the muscles, their nerves of supply, other tissues that are secondarily affected, and the cause that is responsible for the paralysis. In cases where the cause is irremovable and progressive, as, for example, in progressive muscular atrophy, paralysis agitans, etc., the degenerative changes in the nerves and the atrophy of the muscles will proceed and little can be expected from electrical treatment. But in cases where the cause can be removed or has ceased to operate, the nerves will recover their function, or regenerate, if their motor nerve cells have not been destroyed.

Nerves recover their function slowly, especially if regeneration has to take place. During this period the muscle is not only out of use, but under conditions that impair its nutrition and that of its nerves and its surrounding parts. By suitable electrical treatment the muscle can be exercised and the condition of the surrounding parts ameliorated. The changes that take place in a paralysed limb may be briefly considered, together with the way in which electrical treatment produces beneficial results. When a muscle is paralysed as a result of injury or disease of its nerve (lower motor neuron) the following changes take place and persist till the nerve has recovered its function.

The muscle ceases all work. It is not even a *resting* muscle, for there is some degree of continuous contraction, or tone, in a resting muscle, and chemical changes are still going on in it. But when there is a lesion of the lower motor neuron, the muscle ceases work entirely. It hangs loosely from its extremities, supported by the skin. Its circulation becomes feeble in the extreme, and the blood supply to the adjoining parts is much impaired. The temperature is lowered and the muscle cannot shiver itself warm. The skin becomes blue and cold, and chilblains develop. The growth of the bone is retarded.

If the nerve fibres regenerate there may be some recovery of function by the muscle, but less in proportion to the length of time during which the muscle has remained in this abnormal condition.

When the lesion causing the paralysis is in the upper motor neuron the condition is less bad when the muscles have passed into a spastic condition, for then there is increased tone, and chemical changes continue, and the circulation is not so impaired. But the muscle cannot contract and its fibres may be to some degree replaced by fibrous tissue as a result of loss of active use, before voluntary power returns. And during the time before the muscles pass into the spastic state their condition is that of muscles in flaccid paralysis.

To prevent these changes a proper circulation must be maintained in the limb, and the muscles and nerves must be artificially stimulated so as to make them work and improve their blood supply. No method of treatment can bring this about more effectively than electrical currents properly applied in the way to be described. Every part is traversed by the current, and every nerve fibre and muscle fibre is stimulated, while all the tissues benefit from the improved blood supply.

The points to which attention should be particularly directed when giving electrical treatment will be considered in order.

The Current to be Used.—The use of an unmodified constant current produces but little stimulation, as shown by the experiments of Debedat (page 147). The current must therefore be modified, so as to bring about the most effective stimulation of the tissues.

It is commonly taught that if the paralysed muscles show normal reaction the faradic current (*i.e.* the current from an induction coil) should be used, while if they show the reaction of degeneration, the galvanic current should be used. This choice of current is probably based on theoretical grounds. Since the times of Duchenne and Remak, each current has been regarded as superior to the other by different observers. The galvanic is the only current that will cause contraction of a muscle showing the reaction of degeneration, but it has to be proved that it is necessary to cause muscles to contract when treating them for paralysis. There is abundant clinical evidence that paralysed muscles showing the reaction of degeneration can be successfully treated by current which cause no contraction, or rather, no shortening. There may, however, be fibrillary contraction without shortening, and there certainly is stimulation of the muscle even if the current is unable to cause shortening. It is possible that one current may be more suitable for some tissues in cases of paralysis, another current for others.

Whichever current be chosen, it is essential that it should be continually varying in strength. Varying currents have a greater stimulating action on the tissues than steady currents and increase their metabolism to a greater extent. A constant current, *unvarying* in strength, such as is so commonly supplied in baths, has little or no value in the treatment of paralysed muscles. A faradic current, *unvarying* in strength, tetanises, fatigues and asphyxiates the muscles (if they respond to this current), and does actual harm.

Some experiments were performed by Debedat to determine the influence, on growing muscles, of different electrical currents applied in different ways. It was found that the rhythmically varied faradic current caused the largest growth (40%); the rhythmically varied galvanic current caused an increase by 18%. These currents were both allowed to flow, during each application, intermittently, periods of flow and periods of rest alternating, each lasting for one second. If the currents flowed continuously without rhythmic variation, quite different results were obtained. The muscles treated by the unvarying galvanic current showed but a slight increase in size; those treated by the faradic current with strength unvaried, diminished in size, and the muscle fibres were damaged, as shown by microscopic examination.

These experiments show the importance of rhythmic variation in the strength of the currents used for their influence on growing tissues, and it is reasonable to conclude that rhythmically varying currents are more effective in the stimulation of paralysed muscles and nerves—a fact which is borne out by clinical experience.

The modifications and variations of the electric current are described in Chapter II., and are summarised in Chapter VIII. It is a very difficult task to decide which of these is the best. If the choice lies between the faradic and galvanic, we may select the galvanic current for treatment of muscles showing the reaction of degeneration, and the faradic current for muscles showing reaction of the normal type.

When the faradic current is used it should be made to vary its strength by the water resistance method (page 132). Or it may be sent through a metronome interrupter, which is made to swing so that the current flows for periods of one second each, followed by a period of rest of equal length. When the metronome interrupter is used a *sudden* tetanus is produced. With the water resistance the tetanus is *gradual*. The latter is more pleasant.

When the constant currrent is used it should be interrupted periodically by the metronome (simple interrupted current), so that periods of flow and no-flow follow one another, each lasting one second.

The sinusoidal current is very valuable in the treatment of paralysis. Not only does it produce good results, whether the muscles show the reaction of degeneration or normal reactions, but it is the simplest to use, and when applied to arm or foot baths or full-length baths very little attention is required. The sinusoidal current is applied to eight baths in the electrical department at St. Bartholomew's Hospital.

When no device for rhythmic interruption or variation is available the effects may be produced by moving one of the electrodes to and fro and on and off the skin.

The Electrodes.—These are of the same design as those previously described, pads of folded lint or towel, covered by felt and metal plate (Fig. 35).

They should be large enough to cover the group of muscles requiring treatment. When the rhythmic variation has to be effected by moving one of the electrodes over the skin, this electrode cannot be so large; its size should be not less than one-third of the area over which it is moved. The small padded disc or button so frequently supplied in the induction coil cases should not be used, as they are much too small. Only a small current can be applied through small electrodes, and the attempt to use a current of adequate strength will cause unnecessary pain. The use of small electrodes in the treatment of paralysis in children is responsible for the statement that electrical treatment of infantile paralysis is impracticable on account of the pain which it produces.

When the paralysis is general, or when it involves an extremity, the best electrode is water—in the Schnee bath or full-length bath, because the largest current can be given with the least amount of sensation. The parts immersed are kept warm; they are surrounded by the water, which acts as a perfectly fitting electrode, and the time that would be occupied by applying the usual electrodes is saved. This saving of time is a matter of importance in hospital practice.

If the lower limbs are to be treated, the full-length bath is best. If the lesion responsible for the paralysis is in the spinal cord, the water in the bath should be at a level high enough to include the lesion in the path of the current: otherwise, the pelvis and lower limbs only need be immersed. In the case of the upper limbs, the Schnee bath may be used.

With regard to the *situation* of the electrodes, they should be placed so as to include in the part traversed by the current, not only the affected muscles, but also the affected nerves, and when possible, the site of the lesion responsible for the paralysis. Thus, for example, in paralysis of the extensors of the upper limb caused by pressure or other injury to the musculo-spiral nerve, one electrode should cover the posterior aspect of the forearm, and the other should be placed around the upper arm and shoulder, so as to cover the region of the injury. Or when the Schnee bath is used the opposite arm should be immersed in the other arm bath, so that the current, on its passage from bath to bath, will traverse the seat of the injury.

The situation of the electrodes will vary in each case, according to the part paralysed, and the cause responsible, and the matter will be further considered under the headings of paralysis of different regions.

The Strength of the Current and the Duration of the Treatment.—At the present day stronger applications are made and the duration and frequency are increased, and evidence goes to show that better results are obtained. Bergonié has increased the length and strength of the electrical treatment of infantile paralysis, and he now gives two applications daily, each lasting thirty to sixty minutes. No fatigue occurs, and nothing but good follows. In busy hospital practice treatment cannot be given so frequently, as a rule, and three applications each week, lasting for thirty minutes each, may be given to out-patients. In private practice the consideration of expense will sometimes prevent a patient coming for treatment with sufficient frequency. Under these circumstances it may be advisable for the patient to receive treatment in his own home, where it may be given by a nurse, under instruction and supervision by the doctor. The faradic current may be used, and an induction coil is the least expensive instrument to buy. The galvanic current, from a portable battery, may be used, but the apparatus costs more. Portable batteries may sometimes be had on hire. Whichever current is used, it should be applied with its strength rhythmically varied, and the readiest way to do this at home is to use a movable electrode in the way previously described. Home treatment may be given for fifteen minutes twice daily.

TREATMENT OF PERIPHERAL NERVE PARALYSIS

In the ensuing paragraphs will be considered the electrical treatment of paralysis due to lesions of the peripheral nerves.

The paralysis may be due either to injury or disease of the nerve. Injury of the nerve trunks are most common in those placed superficially, and the injury may be of any degree varying between slight pressure, causing numbness, to bruising, laceration and division, with loss of motor power and sensation in the localities supplied by the nerve or nerves implicated,

They occur more often in the shoulder and arm, and all cases are most interesting from the diagnostic standpoint. Falls, blows, gun-shot wounds, dislocations, pressure (as from the use of a crutch, or falling asleep with the arm over the back of a chair) may produce a musculo-spiral paralysis. Incised wounds about the wrists from broken glass or other causes frequently result in division of the ulnar or median nerves. The first thing to be done in any case of division is to find and suture the divided ends—or if the paralysis is the result of pressure by cicatrical tissue or callus, it must be freed from its surroundings. The case will be referred for electrical treatment at a later date, and if tested, reaction of degeneration will be found in the muscles supplied by the injured nerve.

The paralysis may be due to *disease* of the peripheral nerves. Alcohol, metallic poisons (such as lead and arsenic), gout, syphilis, sepsis, and the specific fevers are common causes. Often there is no discovered cause and we speak of a "rheumatic" neuritis. If a mixed nerve is affected, either by disease or injury, pain may be severe, or, on the other hand, it may be slight or absent. If pain is present, it is a good plan to commence by applying appropriate treatment for the relief of the pain, and leaving the treatment of the paralysis till the pain has subsided or lessened.

The Prevention of Stretching of Paralysed Muscles.—It is very necessary, when treating paralysed muscles, to prevent them from being stretched. Stretching a paralysed muscle hinders and delays its recovery; it is therefore necessary to prevent such stretching, not only during treatment but also in the intervals between the treatment. If the paralysis is confined to one group of muscles, say the flexors or extensors of a joint, the latter can be fixed by means of a supporting splint, so that the paralysed group is completely relaxed. If both flexors and extensors are paralysed, the joint should be fixed in such a position that both groups have an equal degree of relaxation. The supporting splint should be worn in the intervals between treatment. It is advisable, however, to perform a few passive movements of the joint once or twice daily so as to prevent adhesions and consequent fixation or limitation of movement of the joint.

When electrical treatment is to be applied, we are confronted by the difficulty, in cases where the paralysis is confined to one group of muscles, that the faradic or sinusoidal current will cause contraction of the healthy antagonists, not of the paralysed group, when the latter shows the reaction of degeneration. Consequently, if the affected limb is not supported during treatment the paralysed muscles will be actively stretched. Even if the simple interrupted current is used the sluggish contraction which it induces in the paralysed group is preceded by a twitch of the healthy antagonists, so that the former group is momentarily stretched.

To overcome this difficulty, a supporting splint which does not cover the paralysed muscles may be worn so that the electrodes can be placed on the skin. The limb cannot be immersed in water unless the splint is made of some material that is waterproof and non-conducting.

The best method to prevent, during treatment, the stretching of paralysed muscles showing the reaction of degeneration, would be to use a current which would cause contraction of such muscles only and not of healthy muscles. The limb could then be immersed in water without the splint, and the labour of applying electrodes and of holding them in position would be saved. The author has devised a modified method of applying the galvanic current which in most cases will restrict the contraction to the muscles showing the reaction of degeneration. The current is applied, not suddenly at full strength, as is the case when a metronome or make-and-break key are used, but *gradually,* its strength rising less rapidly to maximum. At the same time it is made to flow longitudinally through the muscles.

The most convenient way of causing the more gradual rise of the current strength to the maximum desired is to use a water rheostat like the Galvanoset (Fig. 24). A less elaborate form, working on the same principle, may be used. The milliamperemeter need not be fitted, and the movement of the carbons is best effected by rotating between the fingers a small milled-edge disc. In this way a rapid or slow rise of the current strength can be effected. Further, the direction of the current can be altered by simple alteration of the direction of rotation of the disc.*

To apply the current, the limb can be immersed in water in one of the receptacles of a Schnee bath, care being taken that when the support is removed the limb rests in such a position that the paralysed muscles are not stretched. The electrode is placed in the water at the end where the hand rests (when the muscles of the forearm and hand are paralysed) so as to ensure the flow of the current in a longitundinal direction along the muscle fibres. In the case of the leg and foot, the electrode should be a metal rod covered by a rubber tube except at its immersed extremity. This ensures the entry of the current only at the distal end of the limb and a longitundinal flow along the muscles. If the electrode is not insulated, the current will enter the limb transversely at different levels. To complete the circuit, another extremity can be immersed in another of the Schnee bath receptacles. The current is then made to increase slowly or quickly to varying strengths in both directions, and the effect on the muscles noted. When the best contraction is seen, the strength of the current, direction of flow, rate of increase, should be noted and no further alteration should be made.

When both the flexors and extensors of a joint are paralysed, the tendons can be felt or seen to move, but the joint will remain stationary or move only slightly. In the case of the foot, movement can be prevented by resting the sole on the bottom of the foot receptacle of the Schnee bath with the leg vertical. In the case of the hand, the latter should be placed with its ulnar border on the bottom of the arm receptacle and movement prevented by placing thickly padded bricks in suitable position in the water.

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* If a condenser is introduced into the circuit (placed *in parallel*) the current rises to its maximum, not suddenly, but gradually. The time occupied by the current in reaching its full strength depends on the capacity of the condenser: the larger the capacity, the less rapidly the current reaches its maximum. If, therefore, the part to be treated is included in a circuit containing a condenser (placed in parallel), and the circuit rythmically interrupted, contraction will be confined to the muscles showing the reaction of degeneration. The strength of the current and the capacity of the condenser must be suitably adjusted. This method was suggested by Lapicque.

It must be borne in mind that the current applied in this way will, if it is made very strong, cause some contraction of healthy muscles. If the paralysed muscles show much diminution of excitability and the current is increased to a considerable strength, the healthy antagonists will contract, and may then overcome the paralysed group and stretch them. It will then be necessary to take the limb from the vessel in which it is immersed, and apply an electrode to the paralysed group. A pad electrode can be used, and it should be fixed over the tendinous ends of the affected muscles, so that the current will flow longitudinally. If the muscles have a still lower degree of excitability, both electrodes may be placed on the muscles, one at the proximal end, the other at the distal end.

The galvanic current, applied in the way described, produces an even, gradual contraction, not a tetanus. It causes no unpleasant sensation, and it can be very easily graduated during its application.

Facial Paralysis.—The cases that respond best to electrical treatment are those in which the paralysis is due to simple inflammation and swelling of the nerve trunk—cases of Bell's palsy. Here the exciting cause of the neuritis, whatever it may be, disappears in the majority of cases, or ceases to act, and we are left with the damaged nerves and paralysed muscles. The treatment may be carried out in the following way:—If the muscles show the reaction of degeneration, the constant (galvanic) current is to be used. One electrode is connected to the positive pole of the source of current. The hand is placed in contact with it. This is the "indifferent" electrode. The active electrode, made of a metal disc, two inches in diameter, padded with felt (of the same kind as that described and illustrated on p. 175) is soaked in a 2% solution of sodium chloride and connected to the negative pole of the source of current. It is then stroked across the face, and at the same time the current should be turned on and increased till it is as strong as can be borne. The electrode should be stroked across the face successsively over the main branches of the nerve, starting behind and below the pinna (from the region where the nerve leaves the stylomastoid foramen) and ending at the middle line of the face. Here the electrode should be lifted off the skin, so as to interrupt the current, and then be replaced over the foramen and again stroked across the face. The active electrode should be the kathode.

The stroking action causes variation in the strength of the current and stimulation of the muscles and nerves.

Another method of treatment is to cover the whole of the affected side of the face with a pad, cut to the correct shape, and soaked in 1% salicylate of soda. This pad is connected to the negative pole and secured to the face. By placing a rhythmically varying resistance in circuit the current is made to wax and wane, or is suddenly interrupted and resumed.

The first method is the simplest and is easier to apply. The treatment should be given at least twice each week, and for twenty minutes each session. It may be given more frequently—every other day, or even daily if there is no erythema or tenderness remaining from the previous treatment.

If the facial muscles do not show the reaction of degeneration, the faradic current will be sufficient. It can be applied in the same way. The active electrode is soaked in dilute salt solution. A dry wire metal brush may be used instead of the moistened padded disc, and stroked over the dry skin. This produces strong *sensory* stimulation of the skin of the face and influences the facial nerve and its muscles reflexly.

Cases of facial paralysis due to inflammation spreading to the nerve from the middle ear will not be improved until the latter region has received appropriate treatment. Electrical treatment is less likely to produce favourable results in these cases.

Facial paralysis due to a lesion in the upper motor neuron is more likely to recover spontaneously than that in which the lower neuron is involved.

If the onset of contracture of the paralysed muscles is suspected, the galvanic current should be applied *without rythmic variation,* by way of an electrode covering the whole of the affected region. This electrode should be the *anode.* The strength of the current should not exceed 5 milliamperes.

Paralysis of the Shoulder Muscles.—The *trapezius* and *sterno-mastoid* are frequently paralysed, either singly or both together. To perform electrical treatment when the trapezius is paralysed, the indifferent electrode may be fixed to the forearm, or the latter may be immersed in a Schnee arm bath. The other electrode, a metal disc three inches in diameter, padded with felt, should be stroked over the trapezius from insertion to origin, passing, in order, over different parts of the muscle; also over the spinal accessory when the lesion involves the nerve in the neck. (For position of the spinal accessory nerve see Plate I., p. 203).

When the paralysis involves the sterno-mastoid the indifferent electrode should be as for paralysis of the trapezius, and the active electrode a padded disc, one and a half inches in diameter. The latter should be stroked along the muscle and the spinal accessory nerve.

When the paralysis is due to inflammation spreading to the nerve from suppurating tuberculous glands, the latter must receive treatment before electrical treatment of the muscles can be carried out with any prospect of success. When due to injury of the nerve, similar methods may be employed, but the nerve, if it has been accidently divided during surgical operation, must be sutured. When due to spinal poliomyelitis, similar treatment may be given on the chance that some part of the nucleus of origin of the nerve has escaped destruction.

Serratus Magnus.—Paralysis of this muscle may result from injury to the posterior thoracic nerve as a result of blows on the side of the neck or an injury to the shoulder region. It may be the result of neuritis. The greater portion of the muscle lies very deeply, covered by the latissimus dossi and the scapula with its attached muscles. In the axilla some of its digitations, near their origin, are uncovered by muscles. For electrical treatment, a disc electrode may be stroked over the digitations in the axilla. Very little current will reach the rest of the muscle when the electrode is moved over the scapular region, on account of the deep position of the muscle. If the latter reacts normally it can be made to contract by stimulating its motor nerve in its course over the digitations in the axilla. If the muscle shows the reaction of degeneration it can seldom be made to contract.

The Deltoid.—Many cases of paralysis of this muscle are encountered. The paralysis may be the result of blows on the shoulder causing injury to the circumflex nerve in its course through the muscle.

Or the nerve trunk may be compressed by pressure within the axilla, caused, *e.g.* by a crutch-head, or by injury or dislocation of the shoulder. The teres minor is paralysed with the deltoid when the injury involves the nerve trunk before it enters the muscle.

For electrical treatment of the paralysed deltoid, it is advisable, when the paralysis is due to injury, and the injury is recent, to surround the limb in the region of the injury by one electrode (which must cover the deltoid), place the other electrode around the forearm and direct the galvanic current from the former to the latter without varying its strength. This will aid the absorption of fluid and inflammatory products from the region of the injury. The rhythmically interrupted sinusoidal or the simple interrupted current can then be passed between the electrodes. Or the slowly increasing galvanic current (p. 153) may be used. When it is thought that the inflammatory products have been absorbed the constant unvarying current need not be used. Till then, however, the first half of each session of treatment should be devoted to its use. Another method is to immerse the forearm of the affected side in the Schnee bath and to apply the other electrode to the shoulder, fixing it there, or using a moveable electrode and stroking it over the region of the muscle. In the latter method, no rhythmic current regulator is needed.

The Spinati.—Of the other shoulder muscles, the spinati are more frequently found paralysed than the latissimus dorsi, pectorals, teres major or subscapularis; these usually escape. The spinati are paralysed as a result, usually, of injury of the suprascapular nerve. Electrical treatment is applied by stroking a disc electrode over the posterior scapular region. The supra-spinatus is covered by the trapezius and the impra-spinatus is covered, in part, by the same muscle and by the deltoid. The spinati are frequently paralysed with the deltoid.

Paralysis of the Arm Muscles.—The muscles supplied by the *musculo-spiral nerve* and its branches (triceps, branchio-radialis, supinator brevis and the extensors of the wrist, fingers, and thumb) may be paralysed as the result of injury or of disease of the nerve. The injury may result from gunshot wounds, from dislocation of the head of the humerus (in the latter case other nerve trunks may be injured as well), or it may result from fracture of the humerus or involvement of the nerves in the callus. The triceps will escape if the nerve trunk is injured below the origin of the branches to this muscle. The nerve trunk may be damaged by pressure from a crutch-head or the back of a chair.

Apart from injury, the muscles may be paralysed from neuritis. Chronic lead poisoning and alcoholic excess are the common causes of this neuritis. The triceps usually escapes, leaving the forearm muscles paralysed, so that wrist-drop is produced. In lead poisoning the brachio-radialis is said to escape.

Before electrical treatment is commenced the cause of the paralysis must be removed wherever possible. For the treatment, one electrode is placed on the limb so that the current can traverse the site of the lesion. If the lesion is in the region of the shoulder, it can be placed on the limb of the opposite side, the other on the posterior aspect of the forearm. The paralysed muscles should be supported by a splint applied to the anterior aspect of the forearm, so as to prevent their extension by the antagonistic muscles. The splint should also be worn between the sessions of treatment

The common causes of paralysis of the muscles supplied by the ulnar and median nerves are injury in the region of the elbow, or shoulder, or wrist.

The injury may be a dislocation of the joint or fracture in its region; other nerve trunks in the neighbourhood may be simultaneously injured. Gunshot injury is, during war, a very common cause. In the region of the wrist an incised wound is the common cause. Pressure from a crutch-head may also injure the ulnar nerve as well as the musculo-spiral. A cervical rib may cause pressure on the first dorsal nerve root. In this root run some of the fibres that ultimately go to form the ulnar and median nerves; ulnar and median paralysis may therefore be caused by pressure from a cervical rib. The intrinsic muscles of the hand are usually affected; sometimes also the forearm muscles supplied by the nerves mentioned.

Injury or disease of the ulnar nerves results in loss of power, wasting and, often, reaction of degeneration in flexor carpi ulnaris, flexor profundus digitorum (inner half), the hypothenar eminence, all the interossei, two inner lumbricales, and inner head of the flexor brevis pollicis. Later on the proximal phalanges become over-extended, and the distal phalanges flexed, due to the unopposed action of the long flexors and extensors. The hand becomes thin and flat, and the characteristic deformity known as the *claw hand* is produced. There is also loss of sensation in the little finger, ulnar half of the ring finger, and corresponding part of the palm.

The median nerve is sometimes divided at the same time as the ulnar. If injured or diseased there is paralysis, wasting and, often, reaction of degeneration in the abductor pollicis, opponens pollicis, and outer head of the flexor brevis pollicis.

There is wasting of the thenar eminence, and the thumb is everted with the nail facing dorsally. Sensation is lost on the palmar aspect of the thumb, index and middle fingers and on the outer half of the ring finger. It is lost also on the central depression of the palm and inner side of the thenar eminence. These are the events that follow a lesion of the median nerve in the region of the wrist. When the nerve trunk is injured or diseased in the forearm or higher up, the flexors of the fingers and thumb, radial flexor of the wrist, palmaris longus and pronators are paralysed in addition. The treatment of paralysis of the median and ulnar nerves is conducted on the same lines as that of the musculo-spiral.

Erb's Paralysis.—Cases of paralysis of a group of muscles which are not supplied by single nerve trunk are not uncommon. In these the lesion will be found very often in a nerve root as it comes from the spine and before it reaches the brachial plexus. This is known as "root paralysis." If the muscles supplied from each of the nerve roots are known, the operator will be able to state the site of the lesion. A common form of "root paralysis" is that known as Erb's paralysis. It results from disease or injury of the fifth and sixth cervical roots before they join the brachial plexus. The muscles affected are the deltoid, biceps, coraco-brachialis, brachialis anticus and brachio-radialis.

All these muscles are caused to contract in the normal subject by stimulation of Erb's point (see Plate I., p. 203).

It will be also noticed that three nerve trunks are represented in the above-mentioned group of muscles—viz. the circumflex supplying the deltoid, the musculo-cutaneous supplying the coraco-brachialis, brachialis anticus and biceps, and the musculo-spiral supplying the brachio-radialis. The position of the arm and hand in this condition is very characteristic. The arm hangs straight down by the side, and the hand is rotated inwards, so that the palm is looking backwards. It has been humorously referred to as the "policeman's tip" position, which is a fairly accurate description of it. It has also been called "obstetrical" palsy, as it has often resulted from traction on the arm in difficult labour.

The prognosis in any case depends on the nature and severity of the lesion producing it. If due to pressure and involvement by malignant disease it would, of course, be very unfavourable. If due to injury at birth the extent of the injury will determine the nature of the prognosis. In severe cases where the nerves are lacerated or torn out from the cord recovery is practically impossible. Most cases fortunately are less severe than this, and recovery to a greater or less extent is the rule.

Recovery will be assisted and hastened by electrical treatment. Treatment must be kept up regularly and persistently so long as improvement continues.

One electrode should be fixed to the posterior aspect of the neck, so as to cover the cervical enlargement. The other should be stroked over the shoulder, anterior aspect of the arm and radial border of the forearm.

A masseuse or nurse should be instructed to massage the arm once or twice daily for from five to ten minutes at a time, and, while doing so, to hold the limb so as to correct the faulty position. It is also necessary to protect the arm from cold as far as possible, especially in the winter months.

It is important to remember that great care must be taken in dealing with children, so as not to frighten them by using too strong a current at the beginning. Indeed, it is a good rule at the first application not to turn on any current at all, but to have everything else arranged as usual. This gains the child's confidence, and at the next application a very mild current is used. This is gradually increased on subsequent occasions until a sufficiently strong current is applied.

Peripheral Nerve Paralysis in the Lower Limb is much less common than in the upper extremity. It may be caused by injury in the region of the knee joint or penetrating wounds of the sciatic nerve. A neuritis of the sciatica nerve trunk or of its cords of origin may be the exciting cause.

The electricial treatment is conducted on the same lines as for paralysis in the upper limb. The full-length bath is very convenient. The Schnee bath is also useful. If there is foot-droop, a support should be worn so as to prevent passive stretching of the paralysed muscles. In the Schnee bath the support may be effected by resting the sole of the foot on the bottom of the bath with the leg vertical. In the full-length bath the foot may be pressed against the vertical metal electrode at the foot of the bath.

In cases of paralysis of the sciatic nerve where the onset is sudden with much acute pain, the latter should be treated first. When the pain is subsiding, the treatment may be changed to application of the sinusoidal current, rhythmically varied, in the long bath.

TREATMENT OF INFANTILE PARALYSIS

This is one of the most common forms of paralysis met with in the electrical departments of hospitals, and fortunately is one for which a great deal can be done. The seat of the disease is the anterior cornu of the spinal cord, where a more or less extensive damage of the ganglion cells is found. Owing to the fact that the nucleus of origin of the motor nerve of any muscle extends through one or more segment of the cord, it is uncommon for any localised lesion to paralyse any single muscle exclusively, and also—especially if the lesion is small, it is unlikely that any large muscle will be completely deprived of the influence of the nucleus of origin of the nerve which supplies it. Part of its nucleus may be destroyed, while other parts are less damaged or even uninjured.

The teaching that the ganglion cells are either destroyed or uninjured—rendering treatment futile in the one case and unnecessary in the other—is incorrect and harmful. The experience, extending over some years, obtained in the Electrical Department at St. Bartholomew's Hospital, is a direct refutation of it. No case is so extensive or so severe that no good will result from proper and persistent treatment.

The state of the muscles in any case will depend on the severity of the original attack and on the time that has elapsed before coming for electrical treatment. It may vary from slight weakness without wasting or loss of voluntary power to complete paralysis with wasting and loss of response to all electrical or other stimuli. Different degrees may be found in the same case, and while the milder cases tend towards spontaneous recovery, it may be safely claimed that without electrical treatment the recovery is slower and less complete. In the more severe cases where there is wasting and reaction of degeneration, the tendency to spontaneous recovery is very slight, but here electricity is able to do a great deal to improve matters.

When the lower limbs are affected, as is usually the case, the treatment may be conducted in one of two ways. In one, the patient is immersed in warm water in a bath of suitable size. The current may be either a faradic or a sinusoidal, preferably the latter; both must be rhythmically varied. The weakest application must be made during the first session, and stronger applications should be made subsequently. It is very important that the child should not receive strong applications at the beginning of the treatment, when it is unused to it. The application of the treatment in baths is the pleasantest way and children will rarely cry when they are receiving it. There are two baths in the Electrical Department of St. Bartholomew's Hospital for the treatment of infantile paralysis. The mothers bring their children up with great regularity, and the good results that follow correctly applied electrical treatment are seen.

When this treatment is commenced, chilblains, if present, disappear; the skin loses its blue colour and the limb becomes warm, even though, at this stage, no voluntary power of the muscles may have been regained. If the anterior horn grey matter has not been damaged beyond repair, some voluntary power will be recovered and reactions of the normal type will return.

The best results are seen in hospital practice, where question of expense does not arise to cut short what is always a long course of treatment. Where expense has to be considered, an electric bath may be improvised for home treatment from a wooden tub or earthenware foot bath. It is filled with water, and a current from an induction coil is sent through the water by way of two metal plates, one placed at each end of the bath. Rhythmic variation can be effected by slowly sliding the secondary coil over the primary or pulling the metal sleeve slowly backwards and forwards over the iron core. This may be conducted at home and a nurse or masseuse instructed in all the details of the treatment, but where possible some part of the treatment should be performed by the physician, as this ensures thoroughness in at least part of the treatment, and also makes it more easy to keep in touch with the progress of the case.

Another method of electrical treatment of infantile paralysis of the lower limbs is the following. One electrode, in the form of a large, well-fitting pad moistened with warm saline, is placed under the back, covering the lumbar enlargement of the spinal cord and the adjacent region. The other is wrapped round the soles and the rest of the feet. The faradic current is used when the muscles show reactions of the normal type; the galvanic current when there is reaction of degenration. Either current is interrupted rhythmically by a metronome. If the galvanic current is applied a reversing metronome should be used. If normal muscles are present in the limb, and if they contract and stretch the paralysed muscles, the device for causing a slow increase of the galvanic current (described on p. 153) may be used in place of the metronome.

Treatment by stroking a disc over the paralysed muscles (using the galvanic current) is not often tolerated by young children and if it is not changed the parents usually cease to bring them for further treatment.

Massage and manipulation constitute a useful accessory treatment. It is a mistake to say that massage can replace properly applied electrical treatment and procure equally good results. This is particularly true in reference to cases showing blueness of the skin, with chilblain and ulcers. The application of the electrical treatment in the bath causes their prompt disappearance, while massage is generally ineffective for this condition of the skin.

The objection is raised that the electrical treatment stimulates the antagonist muscles (if they are healthy) to contract, so that those which are paralysed are passively stretched. This can be avoided by applying a suitable splint so as to support and fix the part moved by these muscles. (It is to be remembered that if these paralysed muscles show the reaction of degeneration, and if the galvanic current is used to treat the paralysed limb, the healthy antagonists will give a quick twitch, while the paralysed muscles will give a sluggish contraction which will long outlast the quick twitch, thereby causing a passive stretching of the *healthy* muscles.)

In cases of infantile paralysis of the upper limb the bath may be used. The patient is immersed so that the shoulders are covered. If the muscles of the arm, forearm or hand are paralysed the limb should be supported in a horizontal position so that the current can traverse it longitudinally. If no bath is available, an electrode should be fixed to the back so as to cover the spine in the region of the cervical enlargement. The other should cover the arm or forearm or hand. The current should be interrupted by a metronome. Some children will tolerate the stroking of an electrode over the paralysed muscles, if weak current are used.

Periodic examinations are to be made of the condition of the muscles by electrical testing. The electrical reactions will afford a good guide as to the progress of the case. In the most severe cases, in which, at the beginning, no reactions of any kind could be obtained, the first sign of improvement may be a very weak, sluggish contraction. If often happens that the return of voluntary power precedes any marked change in the response to electrical stimuli.

It is useless to commence treatment of infantile paralysis unless prepared to persevere with it. It should be given at least twice weekly, or, better, four times or six times, when possible. Bergonié treats his cases twice daily, for half-an-hour to an hour. There is no fatigue produced and the best results are obtained.

The treatment of infantile palsy should be extended over a period of at least six months, and left off only when it is evident that no improvement has taken place for the same period of time.

TREATMENT OF PARALYSIS DUE TO LESIONS OF THE UPPER MOTOR NEURON

In the preceding paragraphs has been considered the treatment of paralysis due to lesions of the *lower* motor neuron—either the peripheral nerve fibre, or the anterior horn cell. In these the paralysis is of the flaccid type and the muscle show, usually, the reaction of degeneration. When the lesion is in the *upper* motor neuron, the reactions are of the normal type and the reaction of degeneration is not seen. The paralysed muscles may be treated in the way described for peripheral nerve paralysis. The sinusoidal or faradic current should be used. In addition, it may be advisable in certain forms of disease or injury of the central nervous system accompanied by paralysis to apply treatment to the region of the lesion. Further details will be found in Chapter XIV. under Hemiplegia, and Progressive Muscular Atrophy.

CHAPTER X

THE USE OF THE ELECTRICAL CURRENT FOR TESTING THE REACTIONS OF MUSCLE AND NERVE

THE physiological response of muscle and nerve to electrical stimulation may be profoundly modified in cases of disease of these tissues. The determination of the nature of the response is known as the "testing of the reactions," and it affords information that cannot be obtained in other ways, the diagnosis in some cases depending upon it. The testing of the reactions of muscle and nerve forms, therefore, an important part of the investigation of cases of paralysis. The reactions sought are the contractions that follow stimulation, first by the faradic current (known also as the *interrupted* current), second, by the galvanic current (known also as the *continuous* or *constant* current), both currents being applied in succession to the muscle itself and to the nerve trunk that contains its motor fibres.

The Reactions of Normal Muscle and Nerve.—When a muscle or its motor nerve is stimulated by the faradic current it will remain in continuous contraction or "tetanus" so long as the current flows. The contraction is continuous, because this current provides a number of stimuli repeated in rapid succession. The muscle being able to contract in response to each stimulus has not time to relax in the very short interval between two successive stimuli, and so it remains contracted while the current flows. If, however, the interrupter vibrates very slowly a single *quick* contraction or twitch is seen at each moment when the primary current is interrupted.

When the muscle or its motor nerve is stimulated by the galvanic current, the muscle makes a single quick contraction or twitch at the moment when the current *commences* to flow. No contraction is seen while the current is actually flowing. A second twitch is seen at the moment the current ceases to flow (if the current is sufficiently strong). These responses—a continued contraction when the muscle or its motor nerve is stimulated by the faradic current, and a single twitch when they are stimulated by the galvanic current—are the responses of normal muscles and nerves and are spoken of as "reactions of normal type" or "normal reactions." They may be altered in disease.

To understand why it is that a knowledge of the electrical reactions of muscle and nerve can aid in the diagnosis and prognosis of paralysis, why *two* currents have to be used, and why certain reactions mean definite morbid conditions, it is necessary to recall to mind a few simple physiological and physical facts. A clear understanding of these facts will dispel much of the difficulty that confronts the student who approaches the subject of muscle and nerve testing for the first time.

It must be remembered that each of the fibres of which a muscle is composed is supplied by a separate nerve fibre which arises from a motor nerve cell situated in the anterior horn of the spinal cord. This nerve cell with its nerve fibre (or axon) and the termination of the latter on the muscle fibre (the end-plate) is known as the *lower motor neuron*. The *upper motor neuron* is similarly made up of a nerve cell (situated in the motor area of the cerebral cortex) and its axon, which passes from the brain along the spinal cord and terminates by forming a synapsis with the nerve cell of the lower motor neuron.

The muscle fibre, the lower motor neuron and the upper motor neuron are all electrically excitable. Clinically, however, we can only test the two former, and for the present we shall consider the electrical properties of these only. The manner in which they respond to the faradic and galvanic currents, when in a normal state, has already been stated. When either current is passed through a healthy muscle it encounters not only muscle fibres but also nerve fibres lying among them. Both are electrically excitable, but motor nerve fibres are more excitable than muscle fibres, so that the contraction of the latter is due to the impulse received from the stimulated nerve. In other words, the muscle is stimulated *indirectly*—the contraction is the result of an *indirect* stimulus. If the current traversed the motor nerve, away from the muscle, a similar contraction would result, the muscle being again stimulated *indirectly*.

Now suppose that the motor nerve is diseased or injured, and has lost its excitability. If the current is now applied to the muscle, it stimulates the muscle fibres *directly*. The faradic current is unable to cause them to contract. The muscle fibres, however, retain their power of contracting when stimulated by the galvanic current, but the nature of the contraction is quite altered. Instead of a quick twitch there is a slow shortening of the muscle, followed by a still slower relaxation. This sluggish response to the galvanic current is one of the features of the reaction known as the "reaction of degeneration."

We must now enquire why the character of the response of the muscle to the faradic and galvanic currents is altered in the way described when the motor nerve has been injured or diseased. The motor nerve cell exercises influence—"trophic" as it is called—over the contractile substance of the muscle. When this influence is cut off, changes take place in the muscle. It wastes, and its fibres lose their transverse striation, and the nuclei proliferate. It loses its power of contracting in response to electrical stimuli of very brief duration (like those provided by the faradic current). It, however, retains its power of contracting when stimulated by electrical impulses of long duration (which can be furnished by the galvanic current), or by mechanical stimuli. The contraction, as already mentioned, is sluggish, If the nerve fibre is divided and completely cut off from the influence of the nerve cell, it degenerates below the section. The part below the section therefore loses its excitability and conductivity, and stimulation by either current is unable to cause a contraction of the muscle.

It must be explained now why the faradic current is unable to cause a muscle, of which the motor nerve has lost its excitability, to contract; why the galvanic current is able to do so, and why the contraction is sluggish.

The faradic current has already been described in detail (p. 31), but here we may repeat that it is intermittent, each period of flow lasting (at break) 1/1000 sec. when the induction coil is suitably designed. These periods, though extremely brief, are quite long enough to stimulate motor nerve effectively. Consequently, a faradic current is able to cause contraction of a healthy muscle with intact motor nerve supply. If, however, the muscle has undergone the changes which follow injury or disease of its motor nerve, stimuli of much longer duration than 1/1000 sec. are required to cause it to contract. These stimuli can be obtained by using a galvanic current and a make and break key. By pressing down and releasing the key, the current can be made to flow as long as desired. This, then, is the reason why two currents have to be used, one providing stimuli of short duration, the other providing stimuli of long duration. The slow contraction of a muscle deprived of its motor nerve is said to be due to the changes in the sarcoplasm already mentioned. It is believed by some that the contractible substance is of two kinds (1) a quickly contracting substance, for the nutrition of which the nerve cell is necessary; (2) a slowly contracting substance which is independent of the nerve cell. Removal of the influence of the nerve cell is supposed to cause changes in the first substance whereby its function is lost.*

The apparatus required for testing and the practical details will now be described, and then we shall consider the various types of electrical reaction and their significance.

Apparatus for Testing.—In order to test the reactions we require an induction coil, a source of constant current, two electrodes and the necessary conducting wires. A convenient arrangement is a switch-board fixed to the wall or a movable table, to which are attached a rheostat, from which a constant current of suitable strength may be taken from the main, and an induction coil which may be worked by the current from the main. By means of a switch either the faradic or the constant current may be diverted to the patient by way of two terminals fixed to the board. A milliamperemeter is provided, so as to indicate the strength of the constant current that is being used. A commutator is provided, so that the direction of the latter current may be reversed, if desired. A switch-board of the type described is shown in Fig. 23.

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* This explanation is not universally accepted. The sluggish contraction is regarded by some as the natural response of normal muscle fibres when they are stimulated *directly,* without simultaneous stimulation of the motor nerve fibres. In the frog, stimulation of that end of the sartorius which contains no nerve fibres is said to cause a sluggish contraction, while stimulation of the other end (which contains nerve fibres) or of the main nerve. causes a brisk contraction. In the human subject, by the time the reaction of degeneration has developed, the changes in the muscle have taken place, and it is therefore difficult to give the precise explanation of the sluggish response.

If there is no main supply, or if the apparatus is to be portable, a battery like that shown in Fig. 29 may be used. The faradic current should be taken from a coil in which the rate of interruption can be reduced, when required, to once per second. The "Physio" coil (Fig. 18) is provided with an interrupter which can be adjusted so as to vibrate with a frequency as low as this.

Two electrodes are required. One, the "indifferent" electrode, is of the type described and figured on page 97; it should measure six by three inches. The other, the "active" or "testing" electrode, is a metal disc three-quarters of an inch in diameter, covered with chamois leather, mounted on a handle, to which is fixed a closing-key (Fig. 45). By means of this key the current may be sent through the patient when wished.

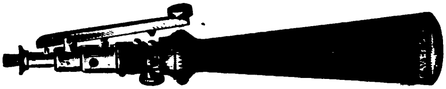

Fig. 45.—Testing Electrode. The chamois-leather-covered metal disc screws on the end. It is not shown in the figure.

Practical Details of Testing.—The beginner is strongly advised to practise the testing of normal subjects before undertaking the examination of abnormal cases. To give a trustworthy report, much practice and experience are required. The beginner can learn the behaviour and peculiaries of the various muscles under examination when normal, and the positions where the testing electrodes should be placed, by repeated examination of normal subjects.

The method which should be adopted will now be described. The same method is used when abnormal subjects are tested. The additional examination necessary when the reactions are found to differ from those seen in health will be described later.

The patient should recline on a couch on his back, with head and shoulders raised. In this position the face, neck, arms, chest, abdomen and lower limbs may be tested. The back of the thigh may be brought into view by flexion at the hip and raising them off the couch. For the back and shoulders, the patient should sit on the couch or lie face downwards. For the gluteal muscles the patient must lie in the last-mentioned position.

The electrodes are moistened with warm salt solution (about 5% strength).

The indifferent electrode is placed on some part of the body away from the muscles that are to be tested. When the upper limbs and shoulder girdle are to be tested, it may be placed over the sternum. In the case of the lower limbs it may be kept in the same situation or placed behind the hips. When the intrinsic muscles of the hand or foot are to be tested the indifferent electrode is better placed on the palm or sole. When testing the face or neck muscles it may be placed under the palm.

The testing electrode is placed over the muscle or nerve of which the reactions are required. The skin in contact with either electrode should be well moistened with the salt solution before beginning the test.

When conducting the test the faradic should always be used first. When the interruption is frequent, the movements of the muscle are more easily seen than when the frequency of the interruption is low enough to produce single twitches instead of a tetanus. Testing with a current interrupted once a second is less painful to the patient, and often yields additional information. Beginners are advised to use the tetanising faradic current, by preference, until they have gained some experience.

The operator should first moisten his own hand with salt solution, lay it on the part to be tested, and place the testing electrode on the hand so that the current passes through the latter before reaching the patient. This not only gives the operator an idea of the strength of the current, but has a reassuring effect on the patient. Strong currents are seldom necessary in electrical testing. The current should be just strong enough to produce a distinct contraction of the operator's dorsal interossei when grasping the patient's limb. This strength will be suitable for most of the limb muscles, but will probably have to be increased when testing some of the intrinsic muscles of the hand and foot, with the indifferent electrode on the palm or sole. The increase is necessary on account of the high resistance of the thick skin of the sole and palm. Muscles that lie close to the surface, like the facial muscles, require weaker currents; those that lie farther away require stronger currents. Muscles like the flexors of the toes, tibialis posticus and extensor longus hallucis, which lie under superficial muscles, require stronger currents. Muscles which have a still deeper situation, like the psoas, are inaccessible for electrical testing. If there is a thick layer of subcutaneous fat, a strong current will be required.

The various muscles that are to be tested are stimulated in turn with a current that is just strong enough to produce a distinct contraction.

It is assumed that the operator has a knowledge of the anatomy of the muscular and nervous systems, including the action and nerve supply of the individual muscles. Such knowledge is absolutely essential if the examination is to have any value.

It is found that when stimulating any normal muscle with a weak current, a contraction can only be produced if the electrode is placed on one spot. With stronger currents some contraction will be observed if the electrode is shifted a little way from this spot, but a stronger contraction will be noticed when the electrode is placed directly on it. This spot is known as the "motor point" of the muscle. Each muscle has its motor point, and it is found to be the surface-marking of the spot where the motor nerve enters the substance of the muscle. This is true of the muscles which lie immediately under the deep fascia. In the case of muscles which are covered by others and lie more deeply (*e.g.*, the extensor longus hallucis), the motor point does not always correspond to the spot where the motor nerve enters the muscle. A thorough knowledge of motor points enables one to perform a test with the smallest possible amount of current and consequently the least discomfort to the patient. Speaking generally, the motor point lies over the middle of the body of a muscle. Thus the beginner, by calling up a mental picture of the muscle which he wishes to stimulate and placing the active electrode over the middle of its body, will be either on the point or so near that very little exploring will discover it. This does not apply to all the muscles, but it applies to a great many, and a knowledge of this fact is a great help and encouragement to the beginner. It is important to point out that it is not necessary, even if it were always possible, to throw the whole of the muscle into strong visible contraction. Some muscles contract strongly and visibly with moderate currents; of this, the biceps in the arm is a good example. The evidence of the contraction of others is obtained by placing the finger lightly over the tendon and then starting and interrupting the current. In this way the slightest contraction becomes manifest. The muscles of which the tendons are gathered about the wrist and ankles are examples. Others, again, are only manifest when the characteristic action of the muscle takes place, such as the supinator brevis, and intrinsic muscles of the hand and foot, and the facial muscles.

Muscles which are too feeble to produce their characteristic action can only be detected by some slight movement on the surface near the electrode.

After having tested the muscles, the operator should test the nerve trunks containing the motor fibres which supply the muscles. To stimulate them sufficiently to produce a contraction, they must be tested where they lie close to the surface. The situations where the nerve trunks are most accessible for testing are shown in the plates following page 202. Stimulation of a normal nerve trunk causes a tetanus of the muscles of which the motor nerve fibres lie in the trunk. If the current is interrupted with sufficient infrequency, single quick twitches are produced.

After testing the muscles and nerves with the faradic current, the galvanic (constant) current is used. The testing electrode is made the *kathode* by connecting it to the negative pole of the source of current. A preliminary trial of the strength of the current should first be made in the way described above, and a current should be used that is just sufficient to cause a twitch when the current starts. It is of importance to use the smallest galvanic current, because this current causes a more painful sensation than the faradic, and if strong it may be unbearable. It is found when testing normal cases with galvanic currents of increasing strength, that a twitch is first noted only at the moment when the circuit is *closed* and the current is *started*. It is only when the current has been much strengthened that a twitch is also noticed at the moment when the current is interrupted. It is noticed, further, that the twitch seen when the circuit is closed occurs sooner (*i.e.* with weaker current) when the testing electrode is the *kathode* than when it is the anode. These twitches are known as the "kathodic closure contraction" (KCC) and the "anodic closure contraction" (ACC). The other twitches occurring when the circuit is opened and the current interrupted are called the "anodic opening contraction" (AOC) and the "kathoric opening contraction" (KOC).*

The *relative* strength of the current required to produce each of these twitches in normal cases is seen in the table below. The *actual* values depend in each case on the thickness of the overlying tissue; when this is thicker a stronger current will be required :

KCC	2
ACC	3
AOC	3·5
KOC	15

When testing the muscles and nerve trunks with the galvanic current, the latter should be sufficiently strong to produce an evident contraction with the weakest current when the testing electrode is the *kathode,* and when the current is started, by closing the circuit. That is to say, the testing current should be just strong enough to produce a distinct KCC.

After testing the muscles with the galvanic current, the nerve trunks should be tested in the same way. The responses of a normal muscle are the same when tested by the galvanic current either over its motor point or its nerve trunk.

When it is desired to repeat the same strength of faradic current at subsequent dates (a procedure which is sometimes necessary) the best plan is to note the position of the secondary coil with regard to the primary. A graduated scale is provided for the purpose. The E.M.F. of the current supplying the primary must be kept constant. This can be done by connecting dry cells to the primary coil. If the main current is used, a voltmeter must be included in the circuit.

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* Although a contraction is obtained when either electrode is placed on the muscle, both when the current starts and when it stops, it must be remembered that only the kathode stimulates when the current starts, and only the anode stimulates when the current stops. In other words, the kathode stimulates at "make," the anode at "break." The reason why the kathode appears to stimulate when the circuit is interrupted (at "break") is the fact that it is impossible, in the human subject, to procure an anodic stimulus without a kathodic stimulus. The current enters on one aspect of the muscle and leaves it on the opposite aspect, or *vice versa* (see page 87). On one side of the muscle is the entering current: on the opposite side is the leaving current, a "virtual kathode." The anodic closure contraction is really the "virtual kathodic" closure contraction.

If the same strength of galvanic current has to be repeated at later examinations the reading of the milliamperemeter should be noted.

The discovery of the motor points, when testing, is not the difficult task that it appears to be to the beginner who inspects the plates after page 202. As already mentioned, he will soon remember where each one is to be found after some practice on his own muscles. It is a good plan also to study the pictures of the dissections of the muscles in a work on anatomy, so as to get a better idea of the position of the various parts.

The Examination of the Reactions of Abnormal Cases.—When the student proceeds to test the reactions of diseased subjects, he may note any of the following variations, when using the faradic current.

(1) There may be no response of the muscles at all (Be sure that the electrode is on the motor point and that it is making good contact, also the indifferent electrode).

(2) The response of the muscles may be much enfeebled. In some cases the weakening will be quite apparent. In others it will be very difficult to decide whether the response is weaker than normal. There is no ready method of measuring the response, and, as already said, there is no way of measuring the strength of the faradic current. Some information may be obtained by comparing

the response given by the same muscle of the opposite side (if healthy) under the same conditions and with the same precautions. The test of the corresponding muscles on the opposite side should always be made. If they are healthy, they form a standard for the particular patient under investigation. After moistening the abnormal side with saline, the opposite side should also be moistened so that the resistance of the skin is made equal on both sides and the strength of the current the same when testing each side. Small differences in the strength of the responses on the two sides are very difficult to detect, but they are not of much importance for diagnosis.

(3) The response of the muscles may be much increased. Here again small increases are not of importance, and are difficult to diagnose with certainty.

If the faradic current, used with its strength as suggested above, causes no contraction, it should be made stronger and the muscle stimulated again. When the strength exceeds a certain value, other muscles in the neighbourhood may contract and joints are moved. When this happens, any contraction of the muscle under examination is masked. Further testing of this muscle should then be postponed until the others, of which the reactions are required, have been examined. The *bipolar* method of testing should then be applied (see page 185).

When testing the nerve trunk the same enquiries should be made as when testing the muscles. The muscles which contract and the strength of their contraction, and the muscles which do not contract, should be noted. In cases of injury to the nerve, the latter should be tested, when possible, both above and below the region of the injury. Care must be taken that the electrodes are so placed that the current cannot pass through any part of the muscle. This precaution is particularly necessary when the galvanic current is used.

When the current is applied to the nerve trunk any of the following variations may be noted in abnormal subjects.

(1) The muscles may give no response.

(2) The muscles may contract but the strength of contraction may be much enfeebled.
the contraction may be much enfeebled.

If no response is obtained, the strength of the current is increased, in the endeavour to obtain a contraction. It can be increased until it is as strong as the patient can bear.

After testing the muscles and nerves with the faradic current, repeat the test with the galvanic current. It is insufficient to bring the test to a close without using the galvanic current, unless the operator can say for certain that the contractions produced by the faradic current are not weakened, and it is sometimes difficult to be sure on this point. And it is incorrect to say that the reaction of a muscle is necessarily normal because it contracts in response to the faradic current. Muscles of which the reactions are certainly abnormal are frequently seen in which there is some response to the faradic current, or a response when this current is made stronger.

When using the galvanic current either of the following variations from the normal may be noted, in abnormal subjects.

(1) The twitch may be smaller or larger than normal, or it may be absent altogether? The same difficulties present themselves when trying to settle the question of the size

of the twitch whether larger or smaller than normal. Small differences are unimportant. In making comparisons with the muscles of the opposite side (if they are normal) the reading of the milliamperemeter will indicate whether an equally strong stimulus is being used on both sides.

(2) The contraction may be quick, like that customary for normal muscles, or it may be slow and sluggish. Under certain circumstances (to be mentioned hereafter) the response of the muscle is quite different from that which is seen in health. Instead of the brisk twitch, there is slow, lazy shortening and relaxation of the muscle that sometimes looks like a peristalic wave. When testing, therefore, with the galvanic current, it must be noted whether the response is a quick twitch or a sluggish contraction.

It will be noted that when the muscle makes this slow response, the current will often evoke a bigger contraction when the electrode is *off* the motor point, and that the biggest responses are obtained when the electrode is at the peripheral end of the muscle. Sometimes it will be found—and this is very important—that the muscle will give a quick twitch when the electrode is placed on its motor point, but a sluggish contraction when placed on the peripheral ends. It is therefore always necessary, when using the galvanic current, to stimulate the fleshy extremities of the muscle and note whether the contraction produced by stimulating the peripheral end of the muscle is slower or larger than that produced by stimulating the motor point.

It is sometimes very difficult to decide whether the contraction is quick or slow, if the corresponding muscle on the opposite side is abnormal, and cannot be used as a standard for comparison. Under these circumstances the muscle should be tested at its motor point, by the faradic current, the interrupter moving slowly so as to cause separate contractions. The galvanic current should then be used—the electrode placed on the end of the muscle—and the contraction compared with that caused by the single induction shocks. Any slowness of the galvanic response can then be observed.

When stimulating the *peripheral* end of the muscle, the indifferent electrode must be placed in some *central* position, so that the current can flow longitudinally through the muscle. For example, when testing the peripheral ends of the forearm muscles near the wrist, the indifferent electrode must be placed on the trunk or upper arm, not on the hand. In the latter position little or no current would flow through the forearm muscles.

When the nerve trunk is tested with the galvanic current, either of the following variations from the normal may be noted.

(1) The muscle may give a feebler twitch than customary in health.

(2) The muscle may not contract at all.

In the latter case the current should be increased until it is as strong as can be borne and the muscle examined to see if any contraction occurs.

Testing with both Electrodes on the Same Muscle.—When the electrical excitability of a muscle is greatly diminished so that strong currents have to be used in the endeavour to cause it to contract, it will sometimes be found that if there are more excitable muscles in the neighbourhood, the latter will contract and may then obscure the movement of those with the diminished excitability. This is frequently found when a group of muscles in a limb has a very low degree of excitability and their antagonists are normal. The normal muscles will contract and cause movement at a joint. The weak muscles are passively stretched and any contraction which might have been caused is overcome. Under these circumstances it is advisable to place *both* electrodes on the muscle that is being tested, replacing the large indifferent electrode by an "active" electrode of the same size as the other "active" electrode. The current is then more concentrated in the muscle which is being tested. Even then, increase of the current beyond a certain strength will cause the antagonists to contract. The joint must then be held by the operator or an assistant and movement prevented.

If there is any residual excitability in the muscle, there is more likelihood of demonstrating it if both electrodes are placed on the muscle.

The Importance of Testing the Nerve Trunks.—Muscles are tested for the purpose of obtaining information on the condition of their motor nerves. The nerve trunks, in which lie their motor fibres, should always be tested because there is less likelihood, if this be done, of failure to demonstrate the existence of excitable and functional nerve fibres. The reason for this will now be shown. If the nerve has a greatly diminished excitability, the maximum current that the patient can tolerate may fail to stimulate it when the point lies some distance below the surface, say on the deep aspect of the muscle. But the same current may be able to stimulate the motor fibres where they are gathered together in a main nerve trunk in a superficial position. Cases occur in which a muscle gives no response to the faradic current, a sluggish response to the galvanic current, but in which some contraction can be caused by stimulating the motor nerve trunk. Further, the muscle may sometimes appear to be inexcitable by *either current,* but stimulation of the motor nerve trunk may cause it to contract.

The testing of the nerve trunk provides more certain information as to *prognosis.* If the nerve is excitable by the faradic or galvanic current, it means that it has not lost its excitability and conductivity, and the outlook is favourable, providing that the lesion is not progressive.

Types of Electrical Reaction of Muscle and Nerve.—(*a*) *Normal.*—If a muscle contracts when stimulated by the faradic current and if, in addition a quick contraction follows stimulation by the galvanic current, the reactions of the muscle are of the *normal type.* If the nerve is stimulated and the muscle responds in the same way, the reactions of the nerve are also of the *normal type.* If the strength of the contraction caused by either current is undiminished the reactions are described as *normal.*

If it is suspected that the contraction is weak, the galvanic current should always be used in addition. Omission to do this may result in a failure to recognise a partial RD. (p. 189).

When the test is being made and the muscle contracts with undiminished strength when the faradic current is used, it may be almost certainly said that its reactions are normal.

(*b*) *Normal Type, but weakened* (*Weak Normal*).—In some cases it will be noted that the contraction produced by the faradic current is obviously weakened. When the galvanic current is used and the twitch is feebler than normal, but not slow, the reactions of the muscles are of the normal type, but weakened. The muscle is said to show "weak normal" reactions. When the nerve is tested, the muscle contracts in the same way as normal muscle with intact nerve, but the contractions are weaker. To the galvanic current the contraction is weak, but quick.

Small diminutions of excitability are not easy to be quite sure of, owing to the difficulty in obtaining at all times exactly similar conditions in all parts of the circuit. The degree of moisture and thickness of the skin, the pressure of the electrode, and its position are all possible disturbing factors. Where the disease is unilateral the difference in the behaviour of the two sides is the best guide, but even here a difficulty arises in the fact that the skin of a paralysed limb sometimes has a much higher resistance. Fortunately the lesser degrees of quantitative change have little or no diagnostic value.

(*c*) In some cases of paralysis it will be noted that the muscles and nerves respond in the normal manner, but the contractions are stronger.

(*d*) In some cases it may be noticed that there is absence of excitability to both faradic and galvanic currents.

(*a*) (*b*) (*c*) and (*d*) are examples of *quantitative* changes in the reactions—differences in degree, not in kind.

(*e*) *Reaction of Degeneration.*—When the muscle does not contract at all when stimulated by the faradic current, and gives a sluggish contraction in response to stimulation by the galvanic current, it is said to show the "reaction of degeneration." The symbol RD is used as an abbreviation for reaction of degeneration. When the nerve is tested, it will be found in many cases to be inexcitable by either current. Some muscles which show RD can be made to contract by stimulating their motor nerves by the galvanic current, and, in a few cases, by the faradic current. The contraction is feeble. In reporting on the reactions of muscles showing RD a statement should be made on the effects noted (if any) on the stimulation of the nerve trunk containing the motor fibres supplying the muscle.

It is sometimes found that muscles showing RD will, when stimulated by the galvanic current, at the moment when the circuit is closed, give a larger contraction when the testing electrode is the *anode* than when it is the *kathode,* whereas the reverse is true for normal muscles. It was formerly thought that this alteration, in which the ACC is greater than the KCC, occurred in all cases of RD. It is, however, by no means a constant feature, and it sometimes depends on the chance position of the testing electrode. This "polar reversal," as it is sometimes called, is no longer included as essential for the diagnosis of RD.

(*f*) *Partial Reaction of Degeneration.*—When the muscle responds, though feebly, to the faradic current, but gives a sluggish response to the galvanic current it is said to show the "partial reaction of degeneration" (PRD). The distinction between this reaction and the weak normal reaction depends, therefore, on the response to the galvanic current, whether slow or quick. As already mentioned under (*a*) and (*b*), the peripheral ends of the muscle should be tested, and if the contraction is larger or slower than when stimulated at its motor points, the reaction may be regarded as a reaction of degeneration. The twitch following stimulation by a single induction shock can be regarded as a measure of the quickness normal for the muscle and it should be compared with the contraction caused by the galvanic current. If the latter is slower, the muscle shows a partial RD.

The anodic closure contraction should also be obtained and compared with the kathodic closure contraction, and if it is larger it provides additional evidence in favour of the reaction of degeneration. But if the anodic closure contraction is smaller than the kathodic, it does not exclude the possibility of the presence of the reaction of degeneration.

When a muscle shows a stronger and slower contraction when it is stimulated at its tendinous end than when it is stimulated at its motor point, it is said to show the "longitudinal reaction." It is really part of the reaction of degeneration.

(*g*) *Myotonic Reaction.*—In Thomsen's disease (Myotonia) it is found that when the muscles are tested with the faradic current, the contraction persists for some seconds (sometimes as long as thirty seconds) after the current has been stopped. The same thing is noticed when the galvanic current is used; instead of a momentary twitch there is a prolonged contraction which lasts while the current is flowing, and persists from five to thirty seconds after it has ceased. This reaction is known as the myotonic reaction. It is characteristic of Thomsen's disease.

When a muscle shows RD the contraction produced by the galvanic current is often seen to persist while the current flows. Such a contraction is called "galvanotonus," or "duration tetanus," but it does not persist when the current ceases to flow. Sometimes the muscle will, after contraction, relax partly but not completely, while the current is flowing. Duration tetanus is sometimes seen in healthly muscles when the galvanic current is strong.

(*h*) *Myasthenic Reaction.*—In myasthenia gravis the muscles are very quickly fatigued and their responses rapidly get weaker during the process of testing, with either faradic or galvanic current. The excitability may even be lost, but it returns after rest. The reaction is known as the "myasthenic reaction."

(*i*) *Rich's Reaction.*—In this reaction a twitch is obtained (using the kathode as the testing electrode) at the moment when the circuit is opened and the current ceases to flow, with a current that is just strong enough to produce a KCC in a normal muscle. In normal muscles it requires a much stronger current to produce a KOC than a KCC.

The different reactions may be tabulated thus :

A. *Muscle.*

Reactions of Normal Type.	**Reactions of Abnormal Type.**
Normal.	I. Reaction of Degeneration.
Weak Normal Reaction.	(1) Partial.
Strong Normal Reaction.	(2) Complete.
Rich's Reaction.	II. Myotonic Reaction.
	III. Myasthenic Reaction.

B. *Nerve.*

Reactions of Normal Type.	**Reactions of Abnormal Type.**
Retention of excitability to both currents.	Loss of excitability to faradic current.
	Loss of excitability to both currents.

Meaning of the Various Types of Electrical Reaction. —*Reaction of Degeneration.*—When a muscle is weakened or paralysed as the result either of injury or disease, the presence of the reaction of degeneration affords evidence on two points : (1) the *site* of the lesion, and (2) the *severity* of the lesion.

1. The *site* of the lesion. The reaction of degeneration indicates that there is a lesion somewhere in the *lower motor neuron*. The lesion may be either injury or disease, and it may be in any part of the lower motor neuron, either the motor nerve cells of the anterior horn of the spinal cord (or, in the case of a cranial nerve, the cells of its motor nucleus) or the motor nerve fibres or their end plates. If the lesion affects the *upper motor neuron* (*i.e.* the nerve track between the cerebral cortex and the anterior horn cells), or if it affects the *muscle* fibres, the reaction of degeneration is not seen.

2. The *severity* of the lesion. RD indicates that the lesion is of some degree of severity. Slighter degrees of injury or disease will produce simply quantitative alteration of the reaction—that is to say, the reaction will be of the normal type, but the contractions to both currents will be weaker.

The reason why RD signifies a lesion in the *lower* motor neuron will be understood if it is recollected that a lesion in the *upper* neuron, or in the muscle, is never followed by the changes in the muscle and its motor nerve already described (p. 172). If the lesion is in the lower motor neuron but not severe, the changes in the muscle and nerve will not occur, and RD will not be found. If then, RD is found, the lesion has been severe enough to cause changes to take place in the muscle which the nerve supplies. The *nature* of the lesion, whether injury or disease, cannot be decided from the reactions. The *progress* of the lesion, whether increasing or diminishing, can be estimated, in some cases, by testing the reactions at intervals. Further reference to this will be found under Prognosis of RD.

If the muscle shows a *partial* RD, the indication is that the lesion is in the lower motor neuron, but less severe than it would have been if the RD had been complete. Thus in the case of nerve *injury* it may indicate that some of the fibres in the nerve trunk have escaped. If this has occurred, the muscle will contain a mixture of normal fibres (which will respond to the faradic current) and abnormal fibres (which, deprived of the "trophic" influence of the nerve cells, will respond only to the galvanic current and contract sluggishly). Disease may affect the nerve trunk in the same way and cause a similar reaction of the muscle, viz. a partial RD.

In the case of *disease* of the nerve, some of the fibres may have escaped. The muscle will then contain normal and abnormal fibres as in the case of injury restricted to part of the nerve trunk, and will show the same type of reaction, viz. partial RD.

Knowledge of the reactions of the nerve will sometimes yield additional information. When a muscle shows complete RD, stimulation of the nerve trunk containing its motor fibres will, in some cases, cause a contraction, though feeble, of the muscle. This indicates the presence of some nerve fibres which have not lost their excitability. Stimulation of the muscle by the faradic current is unable to reveal them in their intra-muscular position because they lie too deeply, the density of the testing current being too low in this deep position to act as an effective stimulus. In some cases, faradic stimulation of the nerve trunk will cause the muscle to contract : in others the galvanic current is required. In the latter, the condition of the nerve has departed further from the normal than in the former.

If a muscle shows partial RD, stimulation of the nerve trunk containing its motor fibres will cause a stronger contraction than that caused by applying the current to the muscle and thereby stimulating the nerve fibres in their intra-muscular course.

Another conclusion might be drawn from the discovery of the response of a muscle to be partial RD. If some of the fibres of a nerve trunk were injured or diseased while others escaped, the muscle would show partial RD. It is possible that partial RD is the reaction of a muscle of which the contractile substance is in a condition intermediate between that in which it reacts normally to electrical stimuli and that in which it shows complete RD. A slight degree of injury (such as pressure) or disease might remove part of the trophic influence of the nerve cells from the muscles and so cause the latter to pass into an intermediate state. Whether we regard partial RD as indicating this supposed intermediate state of the muscle or the presence of a mixture of normal and abnormal fibres, this reaction indicates that the lesion of the nerve is less severe than it would be if complete RD were present.

Weak normal reactions are found in milder cases of injury or disease of the lower motor neuron—cases which would, if more severe, show RD. They signify that if there is injury or disease of the lower motor neuron it is insufficient to cause loss of excitability or conductivity of the latter.

Increased normal reactions occur in cases of paralysis in which there is a lesion in the upper motor neuron, and the muscles are spastic.

Vigorous reactions of the normal type are seen in tetany. The production of a stronger contraction under the anode when the current is stopped than that produced under the kathode when the current is started (i.e. a greater AOC than KCC) is said to be a constant phenomenon in tetany. In this disease, the disappearance of anelectrotonus is a stronger stimulus than the appearance of katelectrotonus.

The myotonic and myasthenic reactions are characteristic of the diseases known as myotonia (Thomsen's disease) and myasthenia gravis.

Rich's reaction is supposed to occur in muscles paralysed as the result of pressure on the nerve trunk.

Course of the Reaction of Degeneration: its First Appearance.—The reaction of degeneration does not appear at the onset of disease or injury of the nerves, even when these have been completely interrupted. *After complete division* of its nerve the muscle ceases to respond to the faradic current in from four to seven days, while, according to Sherren, the sluggish response to stimulation with the galvanic current begins about the tenth day. The RD is therefore complete on the tenth day, in cases in which the nerve has been completely interrupted. The actual time at which RD is fully developed probably varies in different cases, according to the exciting cause.

If the muscle has been completely and permanently cut off from the anterior horn cells, the reaction of degeneration persists, but becomes slowly and progressively feebler, and, after one year, it may be impossible to elicit any response to electrical stimulation. In several cases of paralysis due to gunshot injury causing division of nerves, loss of excitability of the muscle was complete long before a year had elapsed.

In less severe injury, when the muscle has not been completely cut off from the influence of the anterior horn cells, RD may persist for a longer time and, if recovery takes place, there may be no period during which there is no response to electrical stimuli.

RD may persist for several years. Lewis Jones believed that this persistence of RD indicated that there were still some representations of the muscle in the anterior horn of the spinal cord.

When regeneration of the nerve has taken place, after injury, voluntary power usually returns before electrical excitability of the muscle or nerve. If the testing electrode could be placed in actual contact with the nerve so as to concentrate the current in the latter, contraction of the muscle would probably be caused as soon as, or before, the return of voluntary power. In the conditions under which electrical testing is conducted, the current stimulates the sensory nerves of the skin and the sensation may become unbearable before the current reaches a strength sufficient to stimulate a motor nerve in a low grade of excitability. On tapping the regenerating end of the nerve trunk, a sensation of formication (fourmillement) is experienced in the area originally supplied by the nerve, and this is noticed before the return of voluntary power or of electrical excitability.

Prognosis indicated by RD.—It must not be thought that if a muscle shows the reaction of degeneration it is irreparably damaged. Recovery of voluntary power and return of normal reactions is a frequent occurrence. If the motor nerve cells have not been destroyed, the motor nerves can recover their function, or regenerate. Consequently, if a muscle shows complete RD the prognosis is doubtful and the outlook for complete recovery and return of normal reactions *depends on the cause responsible for the paralysis.* If this is unknown, or if it is an injury of which the extent is not evident, some idea of the outlook can be obtained by testing the reactions of the muscle and nerve at intervals of three or four weeks. If the sluggish response to the galvanic current does not become feebler, the prognosis is as a rule favourable. If the response becomes feebler or disappears the outlook is unfavourable, but even if the excitability of the muscle disappears altogether the chance of recovery is not entirely lost.

If the RD is partial, there is still some physiological and anatomical connection between the muscle and the motor nerve cells in the spinal cord, and the outlook is favourable, providing always that the lesion is not progressive.

A better clue to prognosis is obtained by testing the motor nerve trunk. If the latter retains its excitability to either current, the outlook is favourable, providing again that the lesion is not progressive.

Prognosis of RD in Nerve Injury.—In cases of injury of nerves due to gunshot wounds and other causes, a report on the reactions of the paralysed muscles is frequently required, together with an opinion on the nature of the injury, whether severe enough to call for surgical exploration. If the muscles show reactions of the normal type and the motor nerves retain their excitability, the outlook is favourable, and treatment by electrical and other physical methods will hasten recovery. If the muscles show partial RD the outlook is also favourable and surgical exploration is not indicated. The test of the muscles and particularly of the motor nerve trunk must, however, be repeated at intervals of three or four weeks, so as to ascertain whether the lesion is progressive or not. Scar tissue in the region of a nerve trunk may contract and compress the nerve fibres, and deprive them of their excitability and conductivity, and the partial RD may become complete. When these retrograde changes takes place surgical exploration is desirable.

If the muscle at the first test shows complete RD or no reaction to either current, the nerve trunk should be tested. If stimulation of the latter causes contraction of the muscles, treatment by physical methods should be adopted. The test should be repeated after three weeks have passed. If stimulation of the nerve now causes contraction of the muscles, physical treatment should be continued for another three weeks, and then the test should be repeated. So long as the nerve retains its excitability and conductivity, physical treatment should be continued. If, however, it is found that stimulation of the nerve causes no contraction, the prognosis is very uncertain, but if there is loss of sensation in the region of skin supplied by the sensory fibres in the nerve trunk, the prognosis is unfavourable, and surgical exploration is indicated.

If, at the first test, the muscle shows complete RD or no reaction at all, and stimulation of the motor nerve trunk causes no contraction, and if there is complete loss of sensation in the skin supplied by the nerve, the indication is that the nerve trunk is *completely interrupted,* i.e., no impulses, either motor, sensory or electrical can pass the lesion. But here, again, the prognosis is not necessarily hopeless without surgical aid, because a complete interruption can occur without apparent structural change in the nerve trunk. If, however, after three weeks physical treatment, there is no change, surgical exploration is indicated.

It must always be remembered that the reaction of degeneration is a changing reaction. The various factors which make up the syndrome RD change with the progress of the case, and the reaction of degeneration either merges into a normal reaction, or the sluggish contraction becomes progressively feebler until it disappears, and no response to electrical excitation, either of the muscle or nerve, is obtained.

It will be realised, from what has been stated, that a prognosis cannot be made on one test only. The test should be repeated periodically, so as to ascertain the direction in which the reaction is proceeding. Invaluable help may be derived from a knowledge of the sensory changes in the region supplied by the damaged nerve, and these changes should always be ascertained and recorded. The special value of electrical testing, in diagnosis and prognosis, is due to the fact that the electrical phenomena are *objective* signs, over which the patient has no control whatever.

Defects of the Method of Testing by Faradic and Galvanic Currents.—The method of testing by means of the galvanic and faradic currents has various defects. In the first place, the strength of the faradic current is not, in practice, measurable, while the duration of the separate impulses varies in different coils and is always longer than the shortest to which healthy muscle can respond, and often it is very much longer. A muscle will have passed out of the normal if it requires an impulse as long as that furnished by many induction coils before it will contract. It does not necessarily follow, therefore, that a muscle must be normal because it responds to a faradic current. On the other hand, although the strength of the galvanic current can be measured by the milliamperemeter, the time during which it is allowed to flow is not measured and is always too long.

Testing by Means of Condenser Discharges.—By this method the strength and duration of the impulses is measured. The apparatus consists of a box of condensers which vary in capacity between 0.01

microfarad and 2·00 microfarads. There are ten intermediate sizes. By means of a metronome any one of these condensers can be alternately charged to a known voltage from the main and then discharged through the patient. The duration of the discharge of a condenser depends, (1), on its capacity: the larger the capacity the longer the duration; (2), on the resistance of the circuit along which the condenser discharges: the higher the resistance the longer the duration. The chief resistance in the circuit is the body. For impulses of very short duration the resistance of the body is constant and may be taken as 1000 ohms in the condition under which the test is performed.

The smallest condenser in the box would then give an impulse lasting only 1/24000 of a second, the largest condenser 1/200 of a second. The voltage to which they are charged can be varied; usually it is 100.

To conduct a test, the condenser of smallest capacity is made to discharge through the muscle. If the latter does not contract, the next condenser is used, and if necessary, others of still larger capacity, until a contraction is obtained. The capacity of the smallest condenser, to the discharge of which the muscle will respond, is an index of the condition of the muscle, in terms of the minimum duration of the electrical stimulus required to make it contract. If the capacity of the condenser is known, the duration of its discharge through the resistance of the body (taken as 1,000 ohms) can be read from a table. There is no need to decide whether the contraction is quick or slow.

It may be taken that muscles with reactions of the normal type will require condensers of capacities measured in hundredths of a microfarad (0.01 to 0.09), according to the degree of departure from the normal; muscles with a partial RD require condensers measured in tenths of a microfarad (0.10 to 0.90); muscles with complete RD require condensers of one or more microfarads.

Instead, therefore, of three types of reaction—normal, partial RD and complete RD—we have twelve degrees of departure from normal, each being represented numerically.

After the new apparatus had been used for testing it was soon found that many muscles showing RD could not respond even to the largest condenser (2.00 microfarads). This condenser does not provide an impulse long enough for most cases of RD. Bigger condensers cannot be used, because, when charged to 100 volts their discharge gives too great a shock. The difficulty may be surmounted by including an additional resistance in series with the patient. This has the effect of lengthening the duration of the discharge. Thus by using a resistance of 5000 ohms the discharge of the condensers through the body can be increased sixfold. It is thus possible to increase the duration of discharge of the 2.00 microfarads condenser to 1/30th of a second. Another way of overcoming the difficulty is to use condensers larger than 2·0 microfarads, but charge them to a lower voltage, say 50.

It was further found that muscles showing partial RD varied greatly with regard to the capacity of the condenser required to make them contract. Some required large condensers (tenths of a microfarad), but many others would respond to much smaller condensers. There are thus many varieties of partial RD.

The testing of the reactions of muscle and nerve by condenser discharges has the following advantages. The method is more accurate because we are using *measured* stimuli, their duration varying between the shortest to which normal muscle and nerve will respond and the longest required for the same tissues when in a condition of degeneration. In the older method we use only two stimuli, the faradic and galvanic currents, the duration of both of which are unmeasured, the former being not short enough, the latter too long. The new method yields more information. The degree of deviation from the normal can be expressed accurately, in terms of the length of the discharge that is just able to provoke a response from the muscle or nerve. A test made by the condenser method causes much less pain than that produced by the galvanic current, and it takes less time.

The fact that condenser discharges are *measured* stimuli enables the operator to apply the same stimulus on each occasion when the test has to be repeated later on, so that he can ascertain whether a muscle or nerve requires a longer or shorter stimulus and thereby obtain some idea of the progress made.

The condenser method of testing gives, in some cases, less certain information than the older method. Some muscles with partial RD will respond to condensers of very small capacity, even as small as 0.05 microfarad at 100 volts. It will be impossible, then, to say whether such muscles have a weak normal reaction or a partial RD unless it is tested as well by the faradic and galvanic currents. Further, a muscle with a very low degree of excitability will sometimes require a condenser of 1.00 or more microfarads, even though its reaction may be of the normal type. A further disadvantage of the new method lies in the fact that if large capacity condensers are required to test paralysed muscles, the discharge will spread to other muscles in the vicinity, and if the latter are normal they will contract violently, and so obscure the movements of the paralysed group. If both electrodes are placed on the muscle to be tested, this disadvantage can be partially but not completely overcome.

It may be said, therefore, that it is unsafe to trust entirely to condensers for the purpose of diagnosis. As mentioned above, the fact that a muscle will respond to the discharge from a small capacity condenser does not exclude the possibility that its reaction may be partial RD. On the other hand, if a muscle is tested by the original method and shows partial RD, yet will respond to the discharge from a small capacity condenser, we may say that its nerve is less severely daamged than it would have been if a condenser of large capacity were required, and that the prognosis, other things being equal, would be more favourable. The author has notes of three cases of *complete* RD in which the muscles responded to discharges of condensers of capacity as low as 0.05 microfarad. Two of these were cases of infantile palsy in an early stage, and the condenser reaction indicated, probably, the presence of some undamaged nerve fibres which the other method of testing had failed to demonstrate.

Condenser discharges, especially when small capacity condensers are used, cause no pain, so that the new method may be used for the first test of the muscles of children and nervous adults, so as to gain their confidence.

It may be said, in conclusion, that testing by means of condensers frequently yields information which is not supplied by the faradic and galvanic currents, but that it is unsafe to trust entirely to the new method for diagnosis.

PLATE I

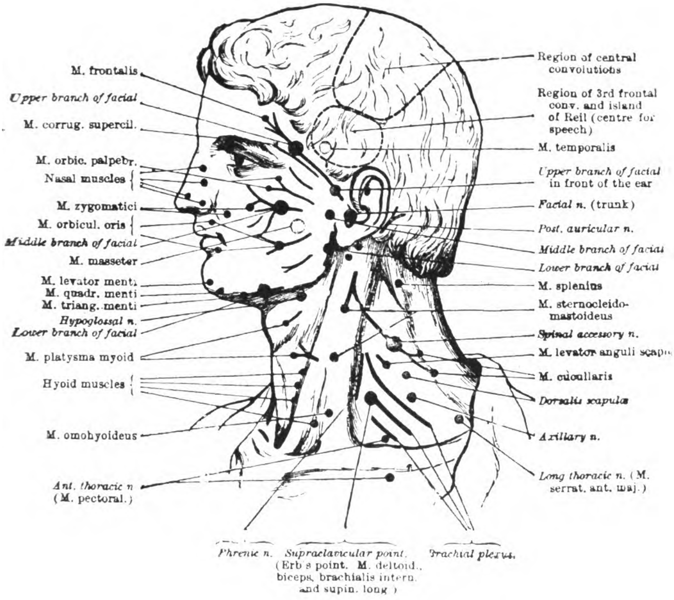

M. frontalis
Upper branch of facial
M. corrug. supercil.
M. orbic. palpebr.
Nasal muscles
M. zygomatici
M. orbicul. oris
Middle branch of facial
M. masseter
M. levator menti
M. quadr. menti
M. triang. menti
Hypoglossal n.
Lower branch of facial
M. platysma myoid
Hyoid muscles
M. omohyoideus
Ant. thoracic n (M. pectoral.)
Region of central convolutions
Region of 3rd frontal conv. and island of Reil (centre for speech)
M. temporalis
Upper branch of facial in front of the ear
Facial n. (trunk)
Post. auricular n.
Middle branch of facial
Lower branch of facial
M. splenius
M. sternocleido-mastoideus
Spinal accessory n.
M. levator anguli scap
M. cucullaris
Dorsalis scapulae
Axillary n.
Long thoracic n. (M. serrat. ant. maj.)
Phrenic n.
Supraclavicular point. (Erb's point. M. deltoid., biceps, brachialis intern. and supin. long.)
Brachial plexus.

PLATE II

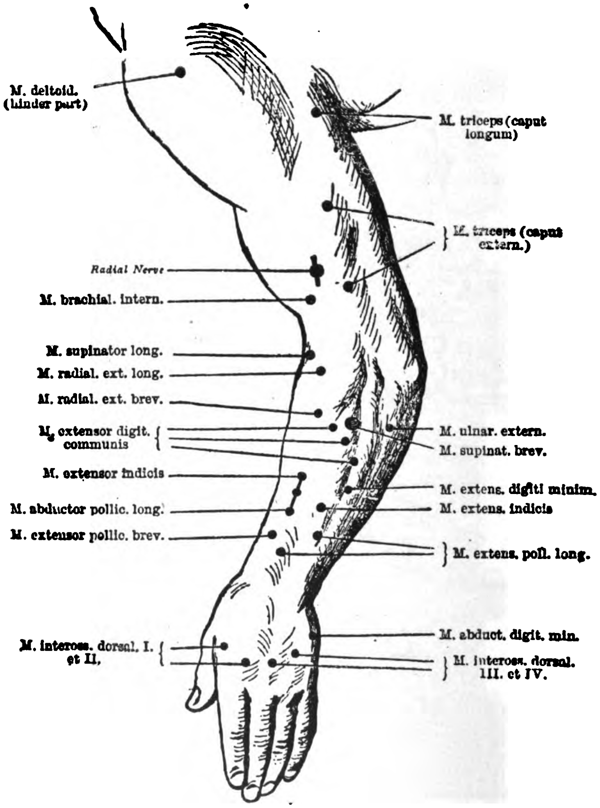

M. deltoid. (hinder part)
M. triceps (caput longum)
M. triceps (caput extern.)
Radial Nerve
M. brachial. intern.
M. supinator long.
M. radial. ext. long.
M. radial. ext. brev.
M. extensor digit. communis
M. ulnar. extern.
M. supinat. brev.
M. extensor indicis
M. extens. digiti minim.
M. abductor pollic. long.
M. extens. indicis
M. extensor pollic. brev.
M. extens. poll. long.
M. abduct. digit. min.
M. inteross. dorsal. I. et II.
M. inteross. dorsal. III. et IV.

PLATE III

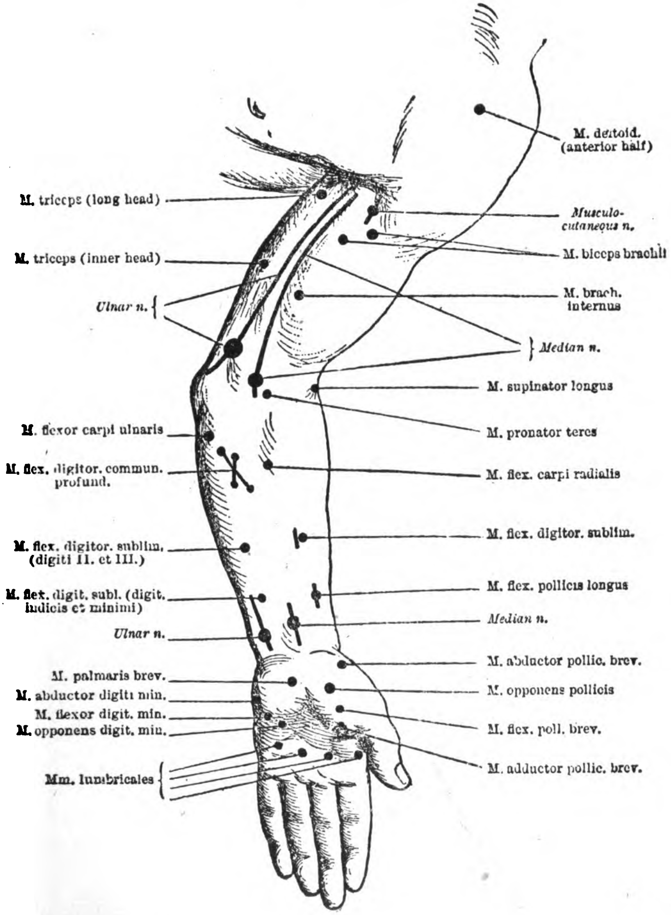

M. deltoid. (anterior half)
M. triceps (long head)
Musculo-cutaneous n.
M. biceps brachii
M. triceps (inner head)
M. brach. internus
Ulnar n.
Median n.
M. supinator longus
M. pronator teres
M. flexor carpi ulnaris
M. flex. digitor. commun. profund.
M. flex. carpi radialis
M. flex. digitor. sublim.
M. flex. digitor. sublim. (digiti II. et III.)
M. flex. pollicis longus
M. flex. digit. subl. (digit. indicis et minimi)
Median n.
Ulnar n.
M. abductor pollic. brev.
M. palmaris brev.
M. opponens pollicis
M. abductor digiti min.
M. flexor digit. min.
M. flex. poll. brev.
M. opponens digit. min.
M. adductor pollic. brev.
Mm. lumbricales

PLATE IV

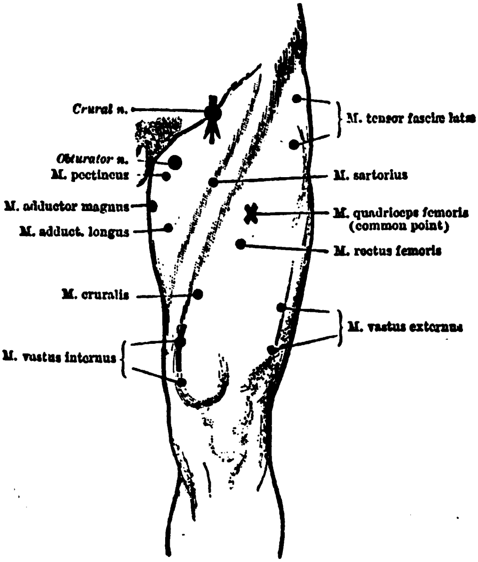

Crural n.
Obturator n.
M. pectineus
M. adductor magnus
M. adduct. longus
M. cruralis
M. vastus internus
M. tensor fasciæ latæ
M. sartorius
M. quadriceps femoris
(common point)
M. rectus femoris
M. vastus externus

PLATE V

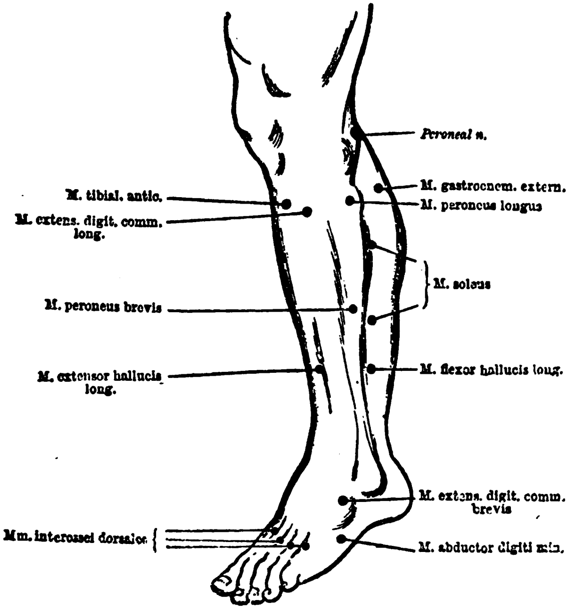

Peroneal n.
M. tibial. antic.
M. gastrocnem. extern.
M. peroneus longus
M. extens. digit. comm. long.
M. soleus
M. peroneus brevis
M. extensor hallucis long.
M. flexor hallucis long.
M. extens. digit. comm. brevis
Mm. interossei dorsales
M. abductor digiti min.

PLATE VI

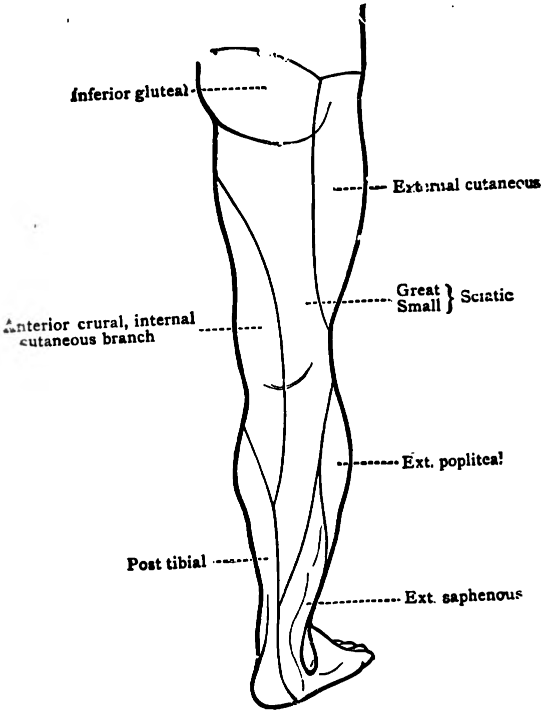

Inferior gluteal
External cutaneous
Great
Small
Sciatic
Anterior crural, internal cutaneous branch
Ext. popliteal
Post tibial
Ext. saphenous

PLATE VII

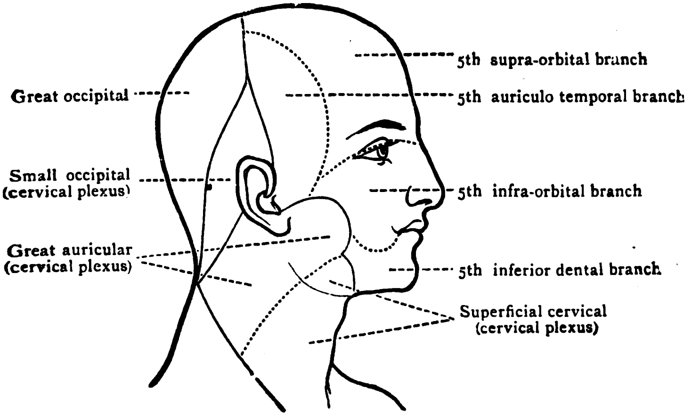

Great occipital
Small occipital (cervical plexus)
Great auricular (cervical plexus)
5th supra-orbital branch
5th auriculo temporal branch
5th infra-orbital branch
5th inferior dental branch
Superficial cervical (cervical plexus)

PLATE VIII

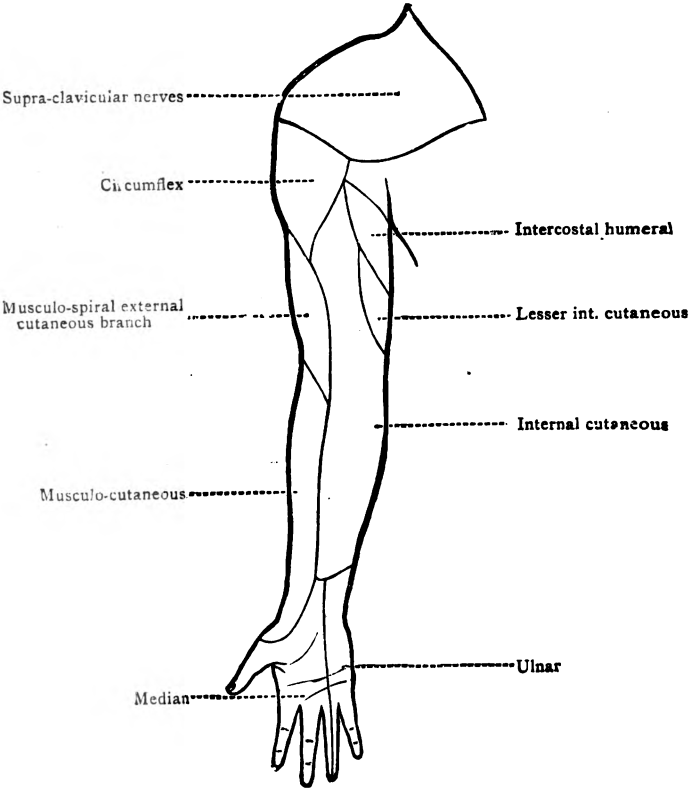

Supra-clavicular nerves
Circumflex
Musculo-spiral external cutaneous branch
Musculo-cutaneous
Median
Intercostal humeral
Lesser int. cutaneous
Internal cutaneous
Ulnar

PLATE IX

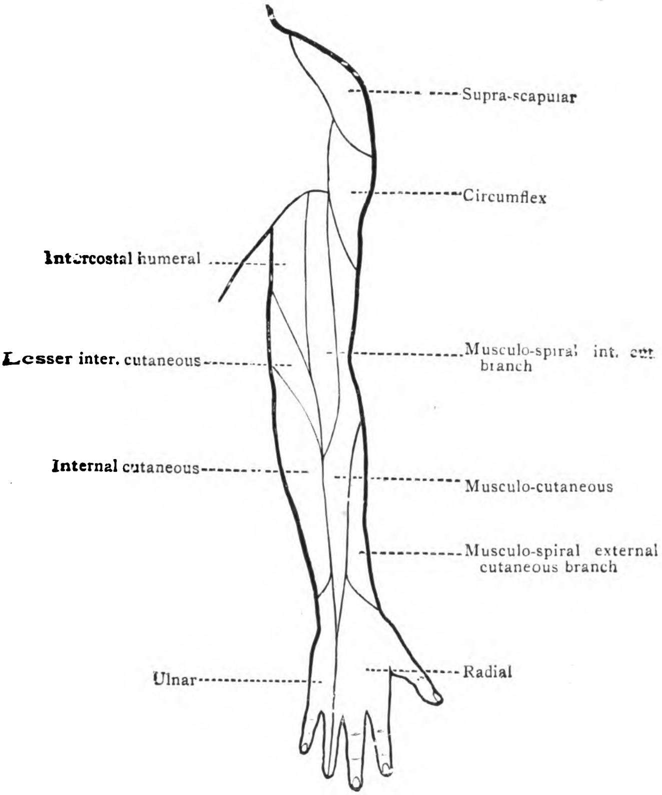

Supra-scapular
Circumflex
Intercostal humeral
Lesser inter. cutaneous
Musculo-spiral int. cut. branch
Internal cutaneous
Musculo-cutaneous
Musculo-spiral external cutaneous branch
Ulnar
Radial

PLATE X

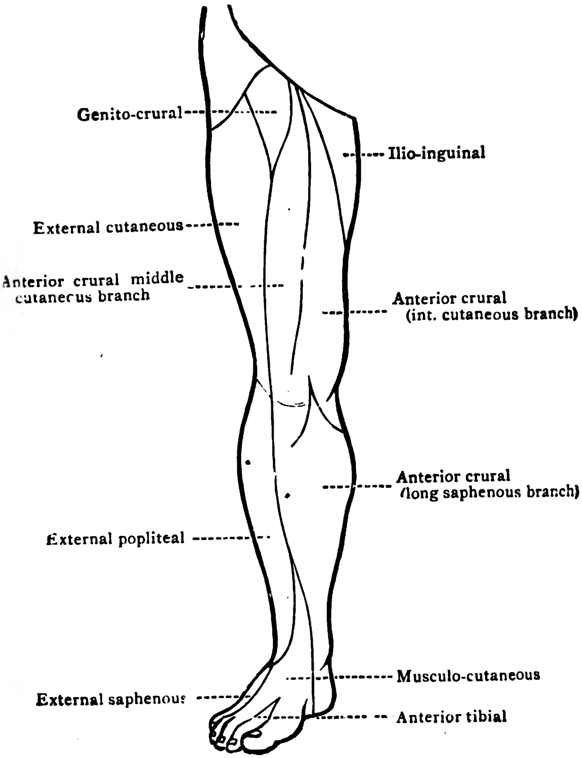
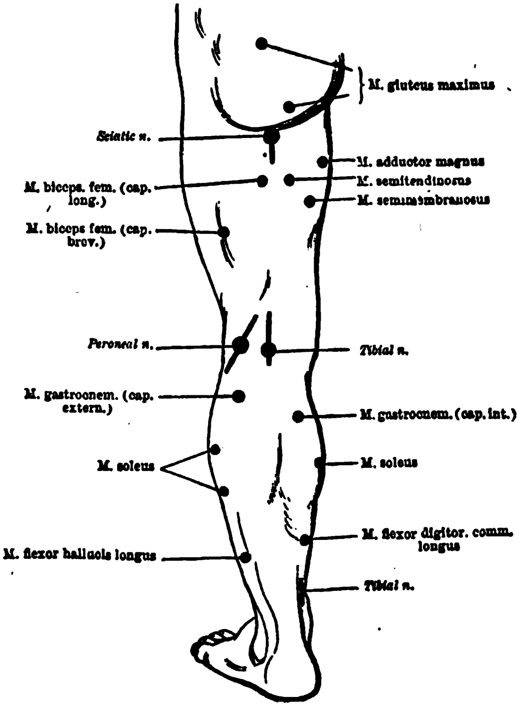

Genito-crural
Ilio-inguinal
External cutaneous
Anterior crural middle cutaneous branch
Anterior crural (int. cutaneous branch)
Anterior crural (long saphenous branch)
External popliteal
Musculo-cutaneous
External saphenous
Anterior tibial

PLATE XI


M. gluteus maximus
Sciatic n.
M. adductor magnus
M. semitendinosus
M. biceps. fem. (cap. long.)
M. semimembranosus
M. biceps fem. (cap. brev.)
Peroneal n.
Tibial n.
M. gastrocnem. (cap. extern.)
M. gastrocnem. (cap. int.)
M. soleus
M. soleus
M. flexor digitor. comm. longus
M. flexor hallucis longus
Tibial n.

CHAPTER XI

HIGH-FREQUENCY CURRENTS

A HIGH-FREQUENCY current is one that periodically reverses the direction of its flow at an exceedingly high rate. A current may be made to reverse its direction any number of times per second, but when the frequency of reversal is sufficiently high the physical properties of the current and its action on living tissues are profoundly altered. The current is no longer able to produce chemical (electrolytic) changes in solution of salts, nor is it able to evoke a response from the excitable tissues. The frequency of reversal may be called *high* when the current is unable to produce these chemical changes or to stimulate muscle and nerve to give their customary response. Such a frequency would be about a million times a second.

How High-Frequency Currents are produced.—A continuous current may be made to reverse its direction periodically by means of a simple apparatus known as a current reverser or commutator. No mechanical apparatus of this kind can produce a sufficiently high frequency of reversal, and the current is generated on quite a different principle.

If a condenser, such as a Leyden jar, is charged and then discharged, the current that flows during the period of the discharge, though of momentary duration, will be a high-frequency current if certain requirements are fulfilled in the circuit along which the discharge takes place. The resistance of the circuit must not exceed a certain value. In the second place, the circuit must be arranged so that self-induction (page 369) can take place along it. Both these requirements will be satisfied if the circuit is constructed of a thick copper wire bent in the form

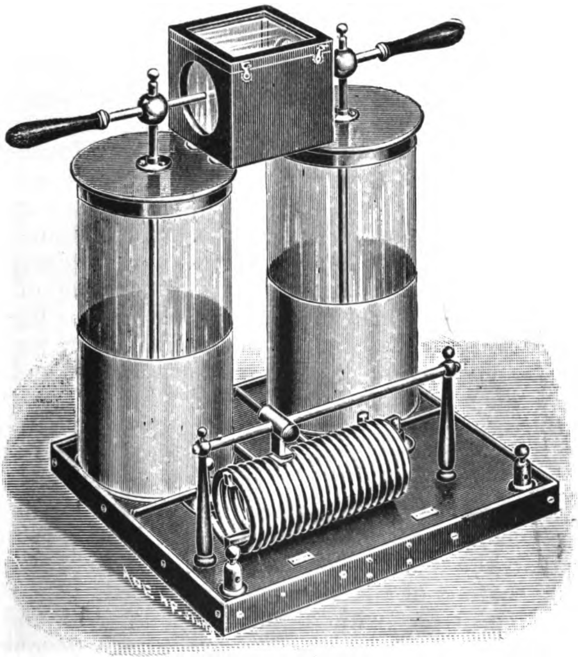


FIG. 48.—D'Arsonval's Transformer.

of a spiral. If the discharge takes place along such a circuit, the current that traverses it will oscillate backwards and forwards from one coat of the condenser to the other, becoming successively feebler with each reversal till it dies away. At this moment the condenser is discharged. All this takes place in a very small fraction of a second, its duration depending on the capacity of the condenser, and the resistance of the circuit and the amount of self-induction that takes place in the circuit. If these factors are known, the number of oscillations per second (*i.e.* the "height" of the frequency) can be calculated.

Apparatus for the Production of High-Frequency Currents.—The arrangement of Leyden jars and wire spiral is shown in Fig. 48, and the plan is shown in Fig. 49 and is known as a D'Arsonval transformer. It is named after Prof. d'Arsonval, of Paris, the pioneer worker in high-frequency currents in their physiological and medical application. It is a simple device for converting or transforming continuous currents or alternating currents of low frequency into others of high frequency. In Fig. 49 *C* and *D* represent the condensers (Leyden jars) in section, each with its outer and inner coat and the intervening insulating material (glass). The inner coatings are connected to the terminals of an induction coil. The outer coats are connected by the wire spiral, *E*. The spiral is made of twenty turns of thick copper wire. It is known as the "solenoid." Sometimes a movable handle is fitted so that the number of coils included between the outer coating of the jars may be varied.

Sliding rods with a ball at one end and an ebonite handle at the other are attached, one to each metal pillar that makes contact with the inner coating of each jar. The space between the balls is the "spark-gap," and it can be varied by sliding the rods to or from each other.

The jars may be charged from a static electrical machine, or from an induction coil. The usual source is a large induction coil of the type used for X-ray work. When the induction coil is used we are really deriving our supply from a constant current (taken from the main or a battery), and the induction coil serves to transform this current, raising its voltage to the necessary degree. The alternating current from the main may also be used to charge the jars after its voltage has been raised

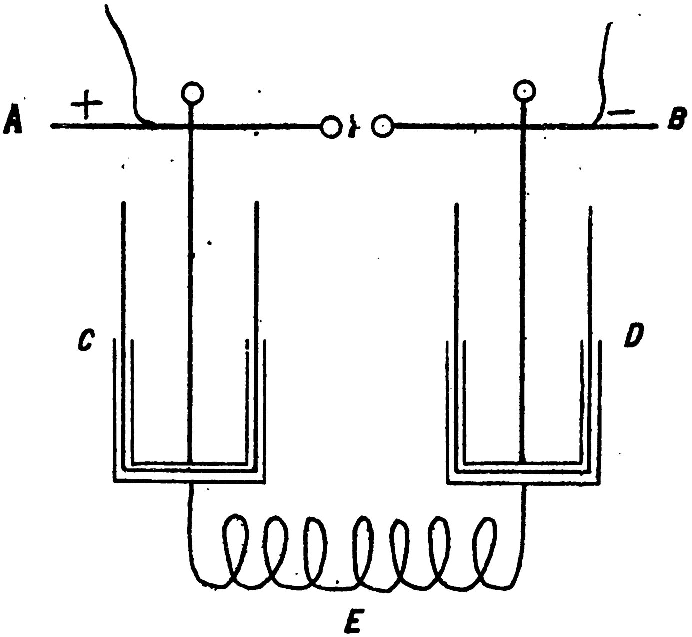


FIG. 49.—Plan of High-Frequency Arrangement.

suitably by a static transformer. When the induction coil is set in action and the spark-gap sufficiently narrowed a torrent of noisy sparks darts across the gap, and at the same time the solenoid is traversed by high-frequency currents. The following events take place. The inner coats of the jars are charged, one positively, the other negatively. Charges of opposite sign are induced on the outer coats. The charges on the inner coats neutralise each other by sparking across the gap and simultaneously the induced charges on the outer coats neutralise each other and a momentary current passes along the solenoid. This current is a high-frequency current, because the solenoid has a low resistance and allows self-induction to take place.

The sparks that appear at the gap seem to follow each other without intermission, and hence it would appear that the charging and discharging of the jars are continuous, giving rise to sustained high-frequency currents along the solenoid. This, however, is not the case. The jars are charged only at the moment when the "break" current is induced in the secondary wire of the coil. They are therefore, charged not continuously but intermittently, the actual number of times per second depending on the rate at which the interrupter makes and breaks the current supplied to the coil. Suppose that this rate is 100 per second. Each 1/100 of a second the jars are charged and discharged, giving rise to a high-frequency current in the solenoid. But the jars take a much shorter time than 1/100 of a second to discharge completely. It may be taken, for jars of the capacity used in the d'Arsonval transformer, as 1/50000th of a second. It follows that every 1/100th of a second a train of high-frequency oscillations lasting 1/50000 traverses the solenoid. The high-frequency current as supplied by the d'Arsonval transformer is, therefore, intermittent, short trains of oscillations separated from one another by very much longer intervals of rest. It may be represented as shown in Fig. 50.

Although the actual resistance of the solenoid to a direct current is extremely low, its resistance to the high-frequency current is very great, even though the potential difference between the outer coats of the Leyden jars is very high, amounting to many thousands of volts. This is because the wire of the solenoid is bent in the form of a spiral with closely adjacent coils so that other currents are induced in the same circuit. It will be remembered that the moment a current begins to flow along a spiral, another current is induced in the same circuit and flows in the opposite direction and impedes it. The induced current is only of momentary duration, so that its only effect on the other current is to impede it at its commencement and so retard its rate of growth to its maximum. But if the inducing current lasts only for the same brief period as the self-induced current it will be opposed considerably and prevented from growing to its full strength. The high-frequency current flows only for a moment in one direction before it reverses, and it is therefore greatly opposed by the currents it induces in its own circuit. If a straight wire connects the ends of the solenoid the high-frequency current will travel by preference along the former, even if it has to spark across a small air-gap in the circuit, and so overcome a high resistance. If the high-frequency current is to be applied to the body it is led off from the terminations of the solenoid by means of suitably insulated cables.

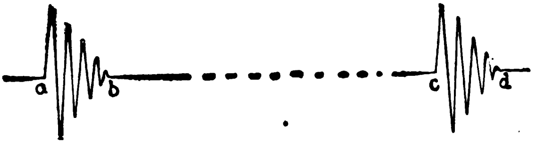


FIG. 50.—Intermittent Trains of Oscillations.

a to b—Train of oscillations, lasting 1/50000th sec.
b to c—Intermission, lasting 1/100th sec.
c to d—Next train of oscillations.

Measurement of High-Frequency Currents.—Alternating currents, whether of high or low frequency, cannot be measured by the amperemeter used for direct currents because their direction is so frequently reversing. The hot-wire amperemeter may, however, be used for the purpose (Fig. 51). In this instrument the current is led through a fine wire, of high resistance. The wire is heated in proportion to the strength of the current, so that it lengthens to a corresponding degree. The degree of lengthening is indicated by a needle moving over a scale calibrated so that a certain number of divisions correspond to a known current passing along the wire.

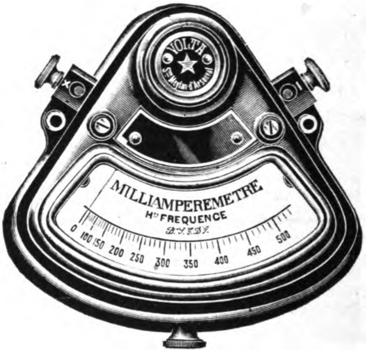


FIG. 51.—Hot-Wire Milliamperemeter.

The current supplied by the d'Arsonval apparatus may reach a strength of 0·5 or 0·6 ampere (500 or 600 milliamperes) when traversing the body.

A complete form of high-frequency apparatus is shown in Fig. 52. The various parts are mounted on a trolley. The Leyden jars are on the lower shelf; in front of them is the spark-gap, enclosed in a glass cylinder to diminish the noise of the sparks. The width of the spark-gap can be varied by means

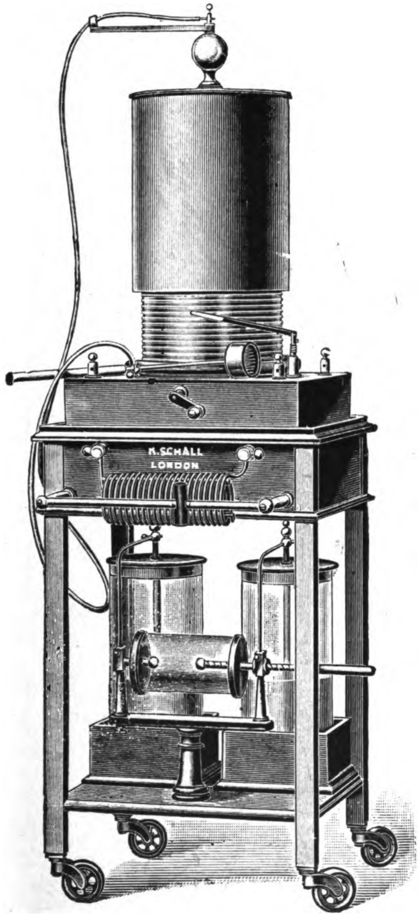


FIG. 52.—High-Frequency Outfit (earlier type).

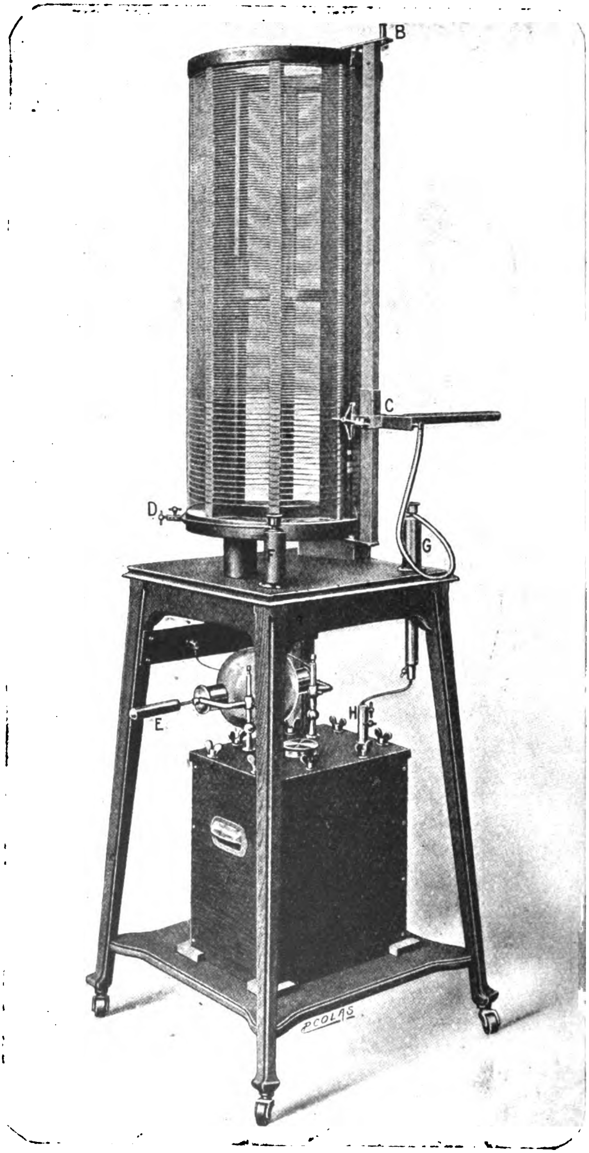


FIG. 53.—Modern form of High-Frequency Apparatus. Plate condensers are fitted. The resonator contains a very large number of turns of wire. A single spark-gap (not a multiple spark-gap) is fitted to this model.

of the sliding handle attached to one of the balls. Above the jars is the solenoid. On the top of the trolley is the "resonator" see later (page 226).

A modern design of high-frequency apparatus is seen in Fig. 53. The condenser is composed of sheets of metal separated by glass, the whole being immersed in oil. It is enclosed in the case on the base of the apparatus. The spark-gap is fixed on the top of this case. It is a multiple spark-gap, that is to say, there are several short gaps in series, not a single long one. These gaps lie between narrow silver discs. The latter are mounted on metal plates and they are prevented from touching by interposing mica washers between the plates. There are nine of these gaps in series. The width of each short gap is fixed, but the total width can be shortened by short-circuiting one or more of the short gaps. The condenser described has a larger capacity than that of two Leyden jars, and if it is discharged across a multiple spark-gap, a current as strong as one or more amperes can be obtained, with the body is circuit.

How High-Frequency Currents are applied to the Body.—(1) *The Direct Method.*—The extremities of the solenoid are connected to electrodes placed in direct contact with the skin. The electrodes are made of sheets of pliable metal, such as copper, lead or tin cut to suitable sizes. They are placed in contact with the previously moistened skin and secured in position by a bandage or sand-bag. The metal should make even contact all over. Instead of placing the metal in direct contact with the skin, a pad of absorbent material, such as lint, soaked in salt solution, may be interposed. Its thickness should be that of eight layers of lint, and its area should be slightly larger than that of the metal plate. It is soaked in a solution of salt so as to enable it to conduct the current readily. The strength of the solution should not be less than 5%. The metal plates are connected to the extremities of the solenoid by thickly insulated cables. Of the electrodes, one is the active electrode and is placed on the part to be treated. The other is the indifferent electrode. It is of larger size than the active electrode and is placed on some convenient part, preferably on the opposite aspect of the body. A second active electrode may be used instead of the indifferent electrode and both placed on the part requiring treatment, one on one side, one on the other.

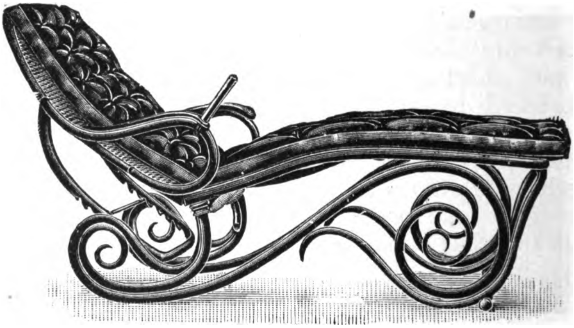


FIG. 54.—Auto-Condensation Couch.

(2) *Indirect Method.*—Instead of placing the indifferent electrode in direct contact with the body it may be placed a little distance away with the intervening space occupied by some insulating material. Such an arrangement is seen in the "condenser couch" or "auto-condensation couch" (Fig. 54). This couch contains a long metal plate fixed under the upholstery and insulated from it. It is connected to one extremity of the solenoid. The patient lies on the upholstery. The other end of the solenoid is attached to a metal handle, fixed to the couch and grasped by the patient, or it may be

attached to an electrode placed on any desired portion of the skin. The couch is called a "condenser couch," because the patient and the metal plate form the armatures of the condenser and the intervening insulating material the dielectric (see page 341 for description of condensers). The patient and the metal plate are alternately charged and discharged with a frequency corresponding to that of the oscillation of the current. The current surges to and fro, into and out of the patient, so that the whole body is brought under the influence of the current, and thus receives *general* treatment, while that part of the body in contact with the electrode receives the greatest concentration of the current, and so gets *local* treatment.

The condenser couch method, or "auto-condensation" method as it is sometimes called, therefore enables both general and local applications to be made, while the metal electrode under the couch obviates the necessity of fixing an indifferent electrode in contact with the skin each time the treatment is given.

Another way of giving general applications of high frequency is to enclose the patient within a greatly enlarged solenoid. The patient stands or sits within the solenoid, the long axis of which is vertical. He does not come in contact with any part of it. His body is traversed by "eddy" currents that are induced within from the coils of the solenoid. This method of application is known as the "auto-conduction" method.

The High-Frequency Effluve.—If a large coil of wire containing several turns be connected to one end of the solenoid, a current of very much higher voltage can be obtained, so that if the free ends of the joined coils be approximated, sparks of much greater length will bridge the gap than if the ends of the solenoid only were brought close together.

The sparks are longer but thinner and less bright. If the discharge is allowed to pass between a plate on one side and a number of points on the other the spark is, as it were, divided up into a number of fine non luminous blue lines which have the appearance of a brush. The larger the number of points the finer the brush. This brush is known as the high-frequency " effluve." A hissing, crackling sound is heard and it grows louder as the brush is made shorter, and when the points are brought sufficiently close to the plate, white sparks pass across the gap.

The coil of wire seen at the top of the high-frequency pedestals shown in Figs. 52 and 53, are attached for the purpose of generating the effluve. It is known as " Oudin's resonator " or simply the " resonator." It should be much larger than those customarily in use if a really efficient effluve is desired. The dimensions of the resonator described below are suitable.

A resonator consists of a wooden cylinder or cage around which are wound several turns of wire, in one layer, each turn being separate from the adjacent turns. It should be not less than nine inches in diameter, and fifteen to eighteen inches high, and wound with about sixty turns of moderately coarse wire—the individual turns are about one-quarter of an inch apart and should be evenly spaced at all points. The lower end of this wire is joined to some part of the thick wire spiral (solenoid) of the high-frequency apparatus, the best point being found by experiment. The upper end of the resonator terminates in a knob or terminal mounted on top of the cage. The wire of the resonator acts as a continuation of the solenoid. It is usual to dispense with the latter and use the lower few turns of the resonator in its stead. If this is done, the lower (proximal) end would be connected to the outer coating of one jar, while the outer coating of the other is attached to a point a few turns higher up. The handle C (Fig. 53) is attached for this purpose, and, by moving it, the connection can be made to the turn desired. The position determines the length and strength of the effluve. The best position may be found by adjusting the position of the handle C. To the upper (distal) end of the resonator is attached an insulated cable and to the free end of the latter is secured the electrode.

Electrode for Applying the Effluve.—The simplest is the "brush" electrode. It consists of a metal disc, one to three inches in diameter, studded on one side with a number of sharp metallic spikes, and secured on the other side to an ebonite handle for the operator to hold. A better form is the so-called "hedgehog" electrode. This is like that described, but instead of a few metal spikes there are a great number of fine metallic bristles (Fig. 55). It provides a very fine brush. The electrode with fewer points produces a coarser and more painful effluve.

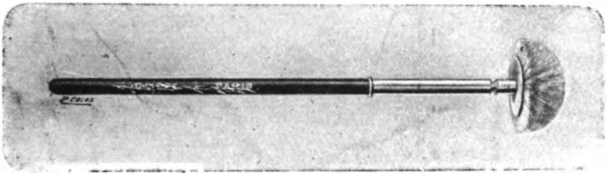


FIG. 55.—The "Hedgehog" Brush Electrode for applying High-Frequency Effluve.

Application of the Effluve.—Before applying the effluve to the patient the apparatus should be adjusted. It will be found that a little alteration of the length of the spark-gap and the relative number of turns in solenoid and resonator will make a great difference in the length of the effluve. Devices for affecting this alteration are provided on each machine. The brush electrode is attached to the upper end of the resonator, and brought gradually nearer to the patient, but not so close that sparks pass. The effluve is stronger if one end of the solenoid or, when this is not used, the lower end of the resonator, is connected to earth or to another part of the patient.

Condenser Electrodes.—Other electrodes are made of closed glass tubes, either filled with some conducting liquid as water or saline solution, or exhausted until the partial vacuum produced becomes a sufficiently good conductor. They are sometimes called condenser electrodes, because the internal conducting medium induces, when charged from the resonator, corresponding charges on the outside of the glass. The current does not actually pass through the glass.

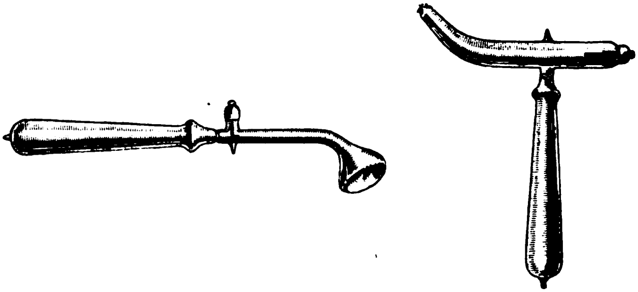


FIG. 56.—Vacuum Electrodes.

The most generally used condenser electrodes are the so-called "vacuum" electrodes (Fig. 56). These are closed glass vessels of various shapes and sizes, from which the air has been sufficiently exhausted to render the residual gas as good a conductor as possible. One end of the tube is pierced by a platinum wire fused into its wall. The tube is attached to an ebonite holder, and the platinum wire is brought into contact with a terminal to which is secured the cable from the top of the resonator.

Application of Vacuum Electrode.—When the current from the induction coil is switched on and the spark-gap gradually widened the air within the tube conducts the currents and becomes incandescent, glowing with a violet light, and as the gap is further widened, blue streak-like sinuous sparks radiate with a crackling sound from the surface of the glass. Before applying the vacuum electrode to the skin, the machine should be adjusted so that the discharge is feeble. The electrode should then be quickly placed on the skin and moved about while the discharge is gradually made stronger until the sensation is as strong as the patient can tolerate. Loud crackling sparks pass between the glass and skin. A pricking sensation is felt and the skin quickly becomes hot and flushed. The electrode is moved over the area requiring treatment. If it is raised a little distance from the skin, a torrent of sparks passes across the gap, producing a vigorous stimulation of the skin and a rapid erythema, and the electrode has to be at once replaced on the skin.

In some of these electrodes the vacuum is so high that X-rays are given off in small amount, but it is doubtful if such rays are formed in sufficient quantity to have any effect.

The Action of High-Frequency Currents on the Body.—When high-frequency currents are passed through the body by the direct method or the auto-condensation or auto-conduction methods there is no perception of the sensations that are customarily associated with the passage of electrical currents. Although the high-frequency current may reach a magnitude of 500 milliamperes or more, there is no perception of pain or tingling. When the density of the current is considerably increased by using electrodes of small size and placing them in direct contact with the skin, the only sensation that is apparent is warmth, and this is, as a rule, slight and not immediately perceived.

We have now a satisfactory explanation of this apparently anomalous behaviour of electrical currents when they oscillate at an extremely high rate, and the matter has been considered in Chapter I., dealing with the mode of action of electricity on the body. It may be mentioned here that it is the movement of ions caused by the current that constitute the electric stimulus and that the high-frequency current oscillates to and fro at a rate so high that the ions are unable to keep pace with it. There is therefore no movement imparted to them by the current, or insufficient movement to constitute a stimulus, so that the current is unable to stimulate the tissues. High-frequency currents can, however, bring about physiological and therapeutic effects, and the question arises, "What is the mode of action of these currents in bringing about the effects observed?" Most probably by the production of heat. There is an actual sensation of heat in the skin, and it may be measured by a surface thermometer. The heat becomes greater as the area of contact between the electrode becomes smaller, thereby increasing the density or "concentration" of the current at its entry, and it may actually cause a burn if the electrode has the form of a wire or needle. The development of heat in a conductor which offers resistance to the current is a well known phenomenon. In the case of the high-frequency current and the body, we have a conductor of sufficiently high resistance and a current of sufficient strength, and when the current flows, heat is developed along its path, both on and within the body. The development of heat *on* the tissues, "epithermy," can be readily demonstrated. The development of heat *through* the tissues, "diathermy," is less easy to demonstrate, as the current produced by the commonly used d'Arsonval type of high-frequency machine is not very strong, and its density diminishes as it passes through the tissues. But it is a necessary consequence of the physical principle stated above that heat should be developed, and as the current passes through the tissues, heat must be developed in the latter, even though it may not be sufficient for the body to feel or a thermometer to indicate. When stronger high-frequency currents (as generated by the diathermy apparatus described in the next chapter) are used, the heat is felt by the body, and it can be measured by a thermometer.

High-frequency currents have, for many years, been used empirically, with varying degrees of success for many maladies. When this form of electrical treatment is to be applied, its mode of action by the production of heat on and within the tissues should be borne in mind, and the question of the advisability of its application and of the benefit likely to follow should be considered from the same point of view.

High-frequency currents have the effect, when the whole body is brought under their influence, of increasing the metabolic changes. D'Arsonval showed that there was an increase in the output of carbon dioxide, of nitrogen and phosphates in the urine, and an increased output of heat. This is what might be expected to follow a very gentle warming of the tissues. High-frequency currents have an influence on the vascular system. Sloan found that their first action was to produce a peripheral vaso-dilatation. The heart then beat more rapidly and counteracted the tendency to fall of blood pressure produced by the vaso-dilatation.

When local applications are made with the vacuum electrodes, a sensation of heat and prickling is produced, if the glass is in contact with the skin; when it is placed a short distance away, numbers of sparks leap across and produce a more violent pricking sensation. The skin soon acquires a vivid erythema, and if the application is made for more than a short time in one situation localised burning may result, especially if the current is strong.

The application of the effluve also produces an erythema of the skin, but more slowly. The stimulation of the skin and the erythema are the result of heating of minute points on which the effluve or sparks fall.

The discharge from the vacuum electrode causes the formation of ozone and oxides of nitrogen as the sparks pass through the air. When the electrode is placed on the skin these gases penetrate for a short distance into the skin. Their odour is perceived for a considerable time afterwards. The effluve also causes the formation of these gases.

The therapeutic action of the high-frequency effluve is due to the stimulation of the sensory nerve-endings in the skin and the resulting erythma. The therapeutic action of the discharge from te vacuum electrode is due to the stimulation of the cutaneous nerve-endings and the heating of the skin. An erythema is produced almost at once, while that caused by the effluve from the wire brush develops more slowly. The heating is probably superficial, on account of the resistance proffered to the current by the thin film of air between the glass and the skin.

The ozone and oxides of nitrogen which are formed during the discharge from the vacuum electrode have germicidal properties, and they may have therapeutic action in the treatment of septic ulcers and infections of the skin.

A powerful effluve is frequently effective in the relief of pain due to irritation or inflammation of nerve. It stimulates the healing of sluggish wounds and ulcers. Septic wounds and ulcers can sometimes be made to heal if the effluve can be directed on all the infected parts. Cases of acne and eczema can sometimes be cured by the application of the vacuum electrode.

The current accompanying the discharge from the brush electrode or vacuum electrode is not really a high-frequency current although it is oscillatory. When the brush electrode is placed close to the skin, just outside sparking distance, and the patient connected to the lower end of the resonator by means of an electrode grasped in the hand, the muscles underlying the region on which the effluve is directed and those of the forearm will be tetanised. The contraction is painless and its strength diminishes to zero when the electrode is moved further away. The interposition of the high resistance of the air gap lowers the frequency of oscillation of the current so that the latter regains some power to stimulate the excitable tissues. The subminimal stimulation of the muscles and nerves when the electrode is placed at a distance just beyond that necessary to cause visible contraction of muscle, may possibly contribute towards the production of therapeutic effects when the effluve is used for the treatment of painful affections.

Massage and high-frequency may be used together, thus combining the effects of massage with those of heat, together with a certain amount of stimulation. One method of combining the treatment is to place the patient on an insulated platform and connect him with the top of the resonator. The masseur quickly places his hand on the part requiring treatment and performs the necessary movement. The smaller the contact between the hand and the patient the greater the heat. If the masseur is connected by his other hand with the lower end of the resonator, more heat is felt. Some stimulation of the skin is caused by fine sparks which pass between the hand and the patient.

Another way of combining the treatment is to place the patient on the condenser couch. The metal plate is connected to the upper end of the resonator, and the patient is connected to the lower end of the resonator by way of an electrode held in his hands. The masseur then places his hand in contact with the patient and performs the necessary movement. If the connections are made to the solenoid instead of to the resonator, more heat and less stimulation are produced.

Use of High-Frequency Sparks for Destruction of Tissue.—It has been mentioned that the high-frequency sparks may produce destruction of the skin. They are actually used for the destruction of abnormal tissue. Pointed metallic electrodes are used and sparks are directed from them on to the part to be treated. The destruction is brought about by the heat at the points on which the sparks fall. The tissue to be destroyed must be superficial and must not extend deeply. This form of treatment has been used with success for flat nævi, port-wine marks, moles and flat warts, and it has proved successful in some cases of lupus and rodent ulcers.

To perform the operation, the patient should recline on a condenser couch which is connected to the solenoid as if auto-condensation treatment were to be applied. A metal point electrode, held by the operator, is brought near to the tissue to be destroyed, so that the point is separated by a short gap, say a quarter inch. The operator must not touch the patient. The apparatus is set in action and the spark-gap is cautiously opened. Sparks then dart across the gap and shrivel up the tissue on which they fall.

This form of treatment by means of sparks is more effectively performed, and with greater precision and control, by means of a diathermy apparatus and condenser couch. See next chapter, page 260.

Malignant growths have also been treated by long high-frequency sparks from very powerful apparatus. Cauterisation by sparks is sometimes known as "fulguration."

CHAPTER XII

DIATHERMY

In the preceding chapter it was pointed out that the high-frequency current provided by the d'Arsonval type of apparatus was intermittent—that is to say, the oscillations occurred in groups, each separated from the proceeding one by a long interval during which there was no current. It was shown that the time occupied by each group of oscillations was very short, while the interval between each group was relatively very long, so that during any period of treatment the body was under the influence of the high frequency for only a very short fraction of the time.

During recent years new types of apparatus have been designed for the purpose of producing high-frequency oscillations that are *continuously* kept up and not intermittent. With a current of continuous high-frequency oscillations, the sensation of heat which with the intermittent oscillations, was slight or even imperceptible, becomes very pronounced and may be unbearable. The heat is developed along the path of the current, both in the superficial and deep parts. In recognition of this production of heat through the tissues as the essential action of sustained high-frequency currents on the body, the word "diathermy" has been devised to describe this mode of electrical treatment. It may be said that all high-frequency currents produce some degree of diathermy, although the heat may not be perceptible or measureable.

"High-frequency" treatment, as generally understood, refers to treatment by the intermittent high-frequency current produced by the d'Arsonval type of apparatus, and the term "diathermy" is reserved for treatment by continuous high-frequency oscillations producing heat as the most conspicous effect. Whether the high-frequency currents are intermittent, producing a trifling amount of heat, or continuous, producing a large amount, the therapeutic action, in both cases, is due to the same effect —viz. the production of heat on and within the tissues.

Diathermy has also been called "thermo-penetration" and "transthermy," terms which also express the results of the action of sustained high-frequency currents of sufficient intensity.

The Production of Sustained High-Frequency Currents.—These currents are generated on the same principle as the intermittent high-frequency current, but the various parts of the apparatus are modified. Instead of Leyden jars, there is a single condenser made of several sheets of metal separated and insulated from each other by mica, glass, or paper soaked in paraffin wax. It is charged from the main. The positive and negative cables from the main are not connected directly to the condensers, because the latter would then be charged only to the voltage of the main supply, and this, at its highest, is not sufficiently high for the condenser. The voltage has therefore to be raised This is done by means of a static transformer. The static transformer is described in detail on page 378, but we may say here that it consists of two coils of insulated wire, both wound on the same iron core, but separately and not in connection with each other. One coil, the primary, is made of a few turns of thick wire. The other coil, the secondary, is made of a large number of turns of fine wire. The current from the main is led through the primary. Currents are induced in the secondary, and their voltage will depend on the number of turns in the latter. The voltage is raised to about 2000 in some models of diathermy machine; in others it is higher, 5,000 or 10,000. The current from the main must be an alternating current, because a direct current passing through the primary would not induce currents in the secondary. If the main supply happens to be a direct current, it must first be transformed into an alternating current by means of a motor transformer. Instead of the thick wire spiral solenoid, a flat spiral like a large clock-spring, is used in the diathermy machine. It is known as the "oscillator." The condenser is connected to the secondary coil of the transformer. One set of its plates is connected to one end of the coil; the alternate set is connected to the other end. The oscillator is included in this circuit.

The different circuits in the diathermy apparatus are shown diagrammatically in Fig. 57.

The spark-gap is quite different from that used in the d'Arsonval apparatus. The discharge takes place, not between two metal rods, but between large metal discs that are very closely opposed to each other without actually touching. There are two of these gaps placed in series. The discs are made of copper and their opposing surfaces, between which the sparks pass, are, in some machines, faced with silver. In some machines the width of the spark-gap is fixed and cannot be varied without dissembling the parts. In others it can be adjusted by simply rotating a handle. Each gap is about 0·25 millimetre wide.

The high-frequency current that is to be applied to the patient is taken, not from the oscillator directly, but from another separate coil like the oscillator. It is known as the "resonator." Its position can be adjusted by a so-called "coupling handle" so that it can be made to lie directly over the oscillator or off it. By altering the coupling the strength of the current in the resonator can be varied. A hot-wire amperemeter is included in the circuit containing the patient and the resonator.

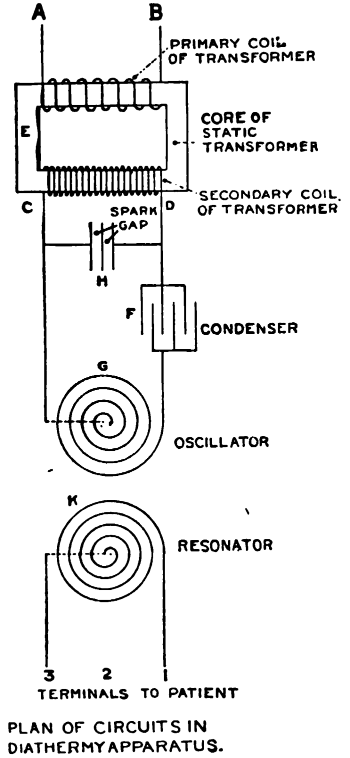

A
B
PRIMARY COIL OF TRANSFORMER
E
CORE OF STATIC TRANSFORMER
SECONDARY COIL. OF TRANSFORMER
C
SPARK GAP
D
H
F
CONDENSER
G
OSCILLATOR
K
RESONATOR
3
2
1
TERMINALS TO PATIENT
PLAN OF CIRCUITS IN DIATHERMY APPARATUS.

FIG. 57.—Diagram showing Circuits in a Diathermy Apparatus.

Explanation of Events taking place in the Diathermy Machine.—It will be assumed that the periodicity of the current supplied to the primary of the transformer is 100. It therefore flows for 1/200 sec. alternately in each direction. It induces in the secondary coil a current of the same periodicity but at a higher voltage, say 2,000. The charging of the condenser by an alternating current can be more easily understood if it be remembered that the ends of the secondary coil (C and D, Fig. 57) are alternately at a positive and negative potential. For the same period one set of sheets of the condenser are at the same positive potential as the end (C), while the alternate sheets are at the same negative potential as the end (D). The condenser discharges across the spark-gap and along the oscillator, the current alternating with high-frequency. It is likely that before the period of 1/200 sec. is over, the condenser is charged many times; each charge is followed by an oscillatory discharge. During each period of 1/200 sec., therefore, there is a succession of trains of high-frequency oscillations along the oscillator and across the spark-gap.

The high-frequency current in the oscillator causes another high-frequency current in the resonator. This is effected to some extent by induction, but chiefly by an entirely different method. A coil in which high-frequency currents are flowing (the oscillator) is a source of electro-magnetic (Hertzian) waves. These waves are propagated into space, and if they impinge on another coil, suitably placed and adjusted, they will cause high-frequency currents in it. The latter coil is said to "resonate," and it is known as the resonator.

The Complete Diathermy Machine.—Various models of diathermy machines are made by manufacturers. They are constructed on the same general plan. A cabinet, with a marble top, is mounted on a trolley. The cabinet contains the transformer, condenser, oscillator and resonator. On the marble slab are mounted the spark-gap, the amperemeter, the coupling handle, and the switches and terminals. The machines differ chiefly in the methods adopted for regulating the incoming and outgoing currents, and in the construction of the spark-gap. In some machines the width of the gap is fixed. In others it can be adjusted without dissembling the component parts.

The machine by Watson and Sons is shown in Fig. 58. The cabinet is shown partly open and the parts in the interior are seen. The spark-gap is adjustable. It is enclosed in an aluminium case and the air inside the latter is replaced by coal gas or petrol vapour.

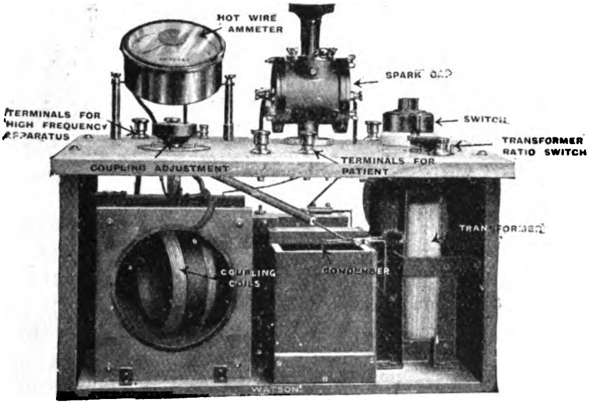


FIG. 58.—Diathermy Machine, by Watson & Sons.

A portable model, suitable for surgical diathermy, and for some medical applications, is made by Schall. It is connected to the *direct* current main. The condenser is charged directly from the main, without elevation of the voltage of the latter. Other models are made by Butt, Dean, and by the Medical Supply Association.

The Diathermy Machine in Action.—When an alternating current is supplied to the primary of the transformer a crackling hissing sound is heard. This is caused by the discharge of the condensers across the spark-gap. The latter is occupied by a film of non-luminous blue light. If wires are conconnected to the extremities of the resonator and brought close together, a torrent of thick dazzling sparks bridges the gap.

Comparision of D'Arsonval with Diathermy Machine.—In the D'Arsonval apparatus an induction coil is used to raise the voltage of the current for charging the condensers. The transformation of the low voltage primary current to the high voltage secondary current in a spark coil is attended by a considerable loss of energy. The secondary current is interrupted and alternating, and in its flow in one direction it does not reach a high voltage (the "make" induced current). The alternating current induced in the secondary coil of the static transformer reaches an equally high voltage in both directions and it is not interrupted. There is practically no loss of energy in the transformation in a static transformer.

The Leyden jars in the D'Arsonval apparatus are charged to a much higher voltage than the plate condenser in the diathermy apparatus, and are charged less frequently. If the spark gap is made as narrow as in the diathermy apparatus in the endeavour to charge the Leyden jars to a lower voltage (and consequently with a greater frequency) the spark gap would become intensely hot. This would reduce the resistance of the gap so low that the jars would be charged to an extremely low voltage, or, possibly, not charged at all. The reason why the very narrow spark-gap in the diathermy machine is formed between large metal discs is the necessity for the prevention of overheating. If the spark-gap of the diathermy machine becomes very hot the current given by the machine is greatly lessened.

The object of providing a multiple spark-gap to the D'Arsonval apparatus is the prevention of overheating. If a multiple spark-gap, like that described on p. 223 is fitted, and plate condensers used instead of Leyden jars, the current from the D'Arsonval apparatus will yield a fair amount of diathermy. A machine by the Medical Supply Association, provided wth plate condensers and a multiple spark-gap, is made for attachment to the induction coil used for X-ray work. It yields a current capable of producing diathermy.

Physiological Action of Diathermy.—The sustained high-frequency currents supplied by the diathermy machine raise the temperature of the tissues whch they traverse, and such physiological effects that have been observed to follow applications of diathermy are the result of this rise of temperature. The subject has not yet received much experimental investigation. Réchou made some observations on the respiratory exchange of a subject during the application of diathermy (quoted by Bergonié, *Archiv. d'Elect. Med.*, 10th March, 1913). He found that the first effect of the diathermy was to increase the intake of oxygen and output of carbon dioxide. As the diathermy continued, it was found that the subject took in less oxygen and gave out less carbon dioxide. The first effect of the diathermy was to increase metabolism, evidently that concerned in the production of heat; the second effect was to diminish it, the artificial introduction of a large quantity of heat rendering unnecessary the production of the customary amount of heat by the body.

The application of general diathermy to the normal subject by means of electrodes grasped by the hands or embracing the forearms is followed by a sensation of heat. The heat is felt first in the narrowest part of the forearm; it then spreads up the arms; afterwards the whole body feels warmer, but the greatest heat is always felt in the lower part of the forearm, where the path for the current is narrowest and the resistance therefore greatest. The subject may sweat profusely after diathermy has been in progress for some minutes, more especially from the upper limbs and face, when the electrodes are applied to the forearms or hands. The frequency of the pulse rises and, in some subjects, the blood pressure falls. Rarely the fall is accompanied by a feeling of faintness and the diathermy must then be stopped.

Proof of the Heating of the Deep Parts.—Experiments on animals have been performed by various workers, and they show that the heat produced by the diathermy penetrates into the deep parts and is not confined to the skin. Thus the hind limbs of animals have been coagulated in their entirety. Electrodes have been placed on the exterior of an animal's skull and the diathermy current passed through the brain. A thermometer with its bulb in the lateral ventricle showed, in one experiment, a rise of 1° Centigrade after ten minutes' diathermy.

In the human subject investigation of the subject is more difficult. If the palms are pressed together and the current directed through them by way of electrodes placed on the back of each hand, a thermometer placed with its bulb between the thenar and hypothenar eminences will show a rising temperature.

How Diathermy is applied to the Body.—Diathermy may be applied so as to raise the temperature of the whole body (general diathermy), or of part of it (local diathermy). The passage of the diathermy current through any part, heats, not only the fixed tissues, but also the blood that circulates through them, so that if the application of the current is for long, and particularly if the current passes along the limbs, the temperature of the rest of the body will be raised by means of the heated blood. Therefore the local treatment becomes, to a greater or lesser degree, a general treatment as well.

(*a*) *General Treatment.*—This may be given on a special form of condenser couch. It was designed by Schittenhelm, and is shown in Fig. 59. The patient lies on sheet ebonite one-eighth of an inch thick, placed on the framework of the couch. Under it lies a large metal sheet divided

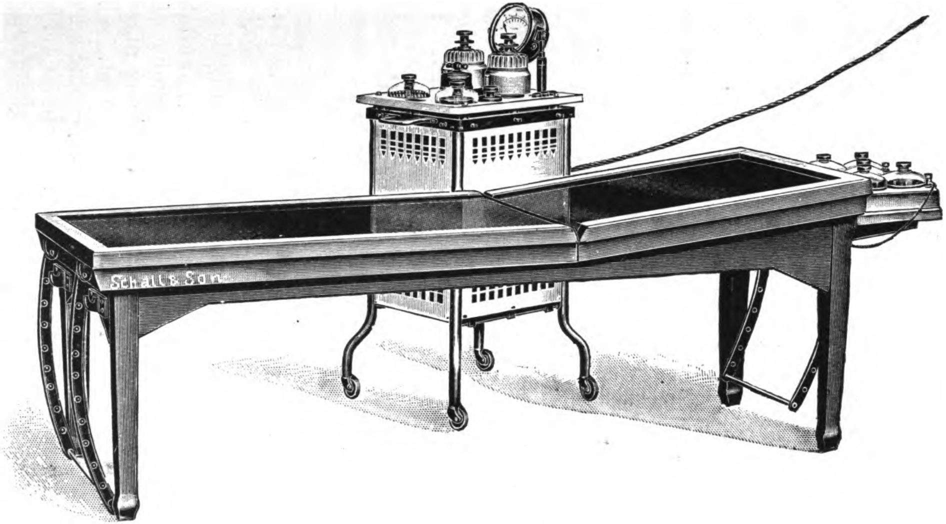


Fig. 59.—Condenser Couch for Diathermy.

into four separate parts. One lies under each lower extremity and one under each shoulder and corresponding side of the trunk. The cables from the diathermy machine are connected to two terminals at the head of the couch. A " changing box " is fixed to the head of the couch. In it are enclosed five cranks, and each of the four parts of the metal sheet is connected to one of these. By turning these cranks into the appropriate positions it is possible to connect either cable from the dathermy machine with any divison or divisions of the metal plate. Suppose that one cable is connected to the division under the right shoulder, the other to the division under the right lower limb. Each division will then become alternately positively and negatively charged, the frequency of the alteration of the charge corresponding to the frequency of the oscillation of the diathermy current. Charges will be induced on the parts of the body in contact with the ebonite sheet over the metal plates. These induced charges will change their sign synchronously with the inducing charges. Consequently induced currents will oscillate through the body between the right shoulder and the right lower limb. By suitable arrangement of the cranks in the changing box the current may be made to oscillate between shoulder and shoulder, or between *both* shoulders and *both* lower limbs, or in any other direction.

A method of obtaining greater heat, and at a quicker rate, is to connect all the divisions of the metal plate to one terminal of the diathemy machine. An electrode is placed round each forearm. They are connected together by a wire and joined to the other terminal of the diathermy machine. This is effected by moving a fifth crank in the changing box. The current, passing along the narrow upper extremities, heats the fixed tissues of the latter and their circulating fluids. The heated blood and lymph circulate through other parts of the body and raise their temperature. The current may be directed along the lower limbs after it has passed, during the first half of the treatment, along the upper limbs.

When applying diathermy on the condenser couch the patient need not remove clothes, but metal, such as coins or keys in the pockets, and watch and chain, are best removed, also corsets, if they contain metal. The patient gradually experiences the sensation of warmth, and it is first felt in the parts in contact with the couch. A watch should be kept on the pulse and blood pressure, for occasionally the latter falls and the patient feels faint. The treatment must then be stopped.

In the absence of a condenser couch, general treatment may be given by applying two electrodes, one to each forearm. The current therefore passes along the arms, across and between the shoulders. In this way the temperature of the arms is raised, while the heated blood passes to the rest of the body and gradually raises its temperature. Electrodes may then be applied to the legs, so that the current passes along them, and across the pelvis, producing local and general heating as before. The current may be directed simultaneously from arm to arm and from leg to leg, by attaching electrodes to each part and using double or bifurcated cables.

(*b*) *Local Treatment*.—The part to be treated is enclosed between two electrodes placed on opposite sides. The electrodes are made of metal plate, and are of different sizes and shapes, oblong, square or circular. They should roughly approximate in size and shape to the part to which they are applied. The metal plates may be placed in direct contact with the slightly damped skin, or an absorbent pad about one-fourth of an inch in thickness, soaked in salt solution, may be interposed. With the latter device a better contact will be ensured when the surface is irregular. Tap-water must not be used to soak the pads with, as it does not contain sufficient saline substances in solution (ions) to conduct the current readily. If tap-water is used, the electrodes become gradually hotter and may cause burns. The strength of the salt solution should not be less than 10%.

When bare metal electrodes are placed in direct contact with the skin, the latter, being relatively dry, and having, therefore, a higher resistance, is more heated than the underlying parts. If a pad soaked in saline solution in interposed between metal plate and skin, the resistance of the latter is lowered. There is, therefore, a more equal heating of the skin and subjacent parts. Consequently, if it is desired to heat the deeper tissues as much as possible, pads soaked in salt solution should be interposed. If bare metal plates are placed on the dry skin, the latter will soon be heated to the maximum degree that can be tolerated before the deep parts receive much heat.

When the electrodes are securely bandaged in position the current is turned on and gradually increased till the patient begins to perceive warmth. The warmth gradually increases and the current may be afterwards further increased till the heat is as much as can be borne without discomfort. The patient's sensation is a sufficient guide to ensure diathermy without burns, but if there is anæsthesia, diathermy cannot be applied without some risk. Nagelschmidt has composed a table showing the maximum current that can be safely borne by the skin with different size electrodes. The latter must make the best possible contact with the skin and the current should not be applied at once in the maximum possible strength.

Local treatment may also be given on the condenser couch. A special terminal on the changing box is connected to an electrode that is placed on the part requiring local treatment. By means of the fifth cranks in the changing box this is brought into connection with one of the terminals of the diathermy machine. By this method the part requiring local treatment will be very effectively heated, while, at the same time, the other parts will receive a less intense but more general treatment. This method is particularly suitable when a large portion of the body, such as the chest or abdomen, is to be subjected to diathermy.

Special electrodes are made for diathermy of special parts. Metal tubes with closed, rounded ends are used for insertion into rectum or vagina. Vacuum electrodes, like those used for high frequency, may also be used for local application, so as to combine the action of the diathermy with that of the oxone and ozides of nitrogen. With vacuum electrodes heat penetration is slight.

Medical Diathermy.—The application of diathermy to medical cases has not been practised long enough in this country to allow a definite statement of the morbid conditions for which it can be applied with benefical results. Maladies and morbid conditions that are likely to benefit from application of heat, are likely to improve further by diathermy. Heat as ordinarily applied warms the skin only. The sustained high-frequency current heats the deep parts as well as the superficial, whereas other methods produce only surface-heating or "epithermy." Inflammation of nerves, accompanied by pain, is often relieved by diathermy when surface heating has failed. In treating peripheral neuritis by diathermy, a method of application which the author has found very successful when tender areas can be discovered, is to apply disc electrodes 1 inch or 1½ inch in diameter to these areas for five minutes, and increase the current till the heat is as strong as can be borne. An indifferent electrode is placed on some other part of the limb or trunk. The treatment may be given daily or on alternate days. In some cases diathermy is successful when all other methods have failed. Diathermy seems to be very successful for gonococcal infection. The gonococcus succumbs if the temperature of its surroundings is raised a few degrees above 98·4° F. By the diathermy current the temperature of the infected part can be raised throughout.

Some excellent results have been obtained in the treatment of gonococcal arthritis. Diathermy has recently been tried in the Electrical Department of St. Bartholomew's Hospital for the treatment of gonococcal infection of the cervix uteri. Cases have been rendered free from the organism, as shown by films and cultures. The permanence of the method is still under trial. The pain and swelling accompanying gonococcal orchitis and epididymitis can be removed by diathermy.

The temperature of the whole body can be raised by general diathermy, and brought into a state of "physiological fever." The condition of lowered vitality, in which there is depression of the functional activity of the organs—cases to which the name "misère physiologique" has been applied—are much benefited by general diathermy, which supplies the heat that the body cannot supply, in its state of impoverished vitality.

Diathermy is also effective in the treatment of the symptoms resulting from arterio-sclerosis. Cardiac pain, with dyspnœa and palpitation, are often relieved by applying the treatment by way of an electrode covering the precordium, the other electrode being placed on the back of the chest. Short applications are made at first, on alternate days. The author has noted complete relief of symptoms in some cases without lowering of arterial blood pressure.

Surgical Diathermy.—By means of the diathermy current it is possible to raise the temperature of the tissues sufficiently high to destroy their vitality. They can be coagulated in situ. The diathermy current can therefore be used to destroy new growths, both innocent and malignant. The coagulation is due to the heat that is produced within the tissues as the current traverses them. Such instruments as the galvano-thermo-cautery and the Paquelin cautery simply char the tissues locally, and, as the latter conduct heat very badly, there is very little spread of coagulation beyond the carbonised cavity. The tissues conduct electricity well, and, as it is the electricity that develops the heat, there is not this limitation to the spread of the coagulation. It is therefore possible, by means of the diathermy current, to coagulate a malignant growth in its entirety " through and through."

The rise in temperature necessary to coagulate a growth is brought about by reducing the size of the electrode in contact with the growth (the active electrode) to that of a needle or small disc or button. The other electrode (the indifferent electrode) covers a large area of skin. The current density will be greatest at the point where the current leaves the active electrode to enter the tissues, and there the temperature reaches the highest value. As the distance below the surface increases, so the current density lessens and the temperature diminishes so that coagulation does not extend below a certain depth. It spreads also to each side of the part covered by the active electrode. The depth to which it extends depends on the following factors.

(1) *The Time during which the Current Flows.*—When coagulation has commenced, the part in con-

tact with the electrode quickly dries. Dried tissue conducts the current badly and sparks make their appearance, muscles in the vicinity strongly contract and the current has to be switched off. A hissing noise of escaping steam precedes the appearance of the sparks and is the signal for the cessation of the current. The depth to which the coagulation has now extended depends on:

(2) *The Extent of Surface of Contact between the Active Electrode and the Tissues.*—If a small surface electrode is used the current density is great at the point of contact with the skin, and the temperature there very quickly rises to a point at which the tissue is dried. Sparks make their appearance and the current has to be switched off soon after it is started, so that there is no time for the coagulation to spread far.

If the electrode makes contact with a larger surface of tissue, a larger mass of tissue—wider and deeper—will be coagulated when the current has passed for the correct length of time. Of course, increase of the surface of contact of the active electrode means a corresponding diminution of current density, and when the latter is lowered beyond a certain degree the temperature of the tissues will not be raised to coagulation point.

The depth to which coagulation spreads depends also on:

(3) *The Vascularity of the Tissue.*—The circulating blood tends to dissipate the heat and may prevent coagulation in the deeper parts where the temperature would, in less vascular parts, be just sufficient to cause coagulation.

As an approximate guide, it may be taken that the coagulation will spread to a depth equal to the maximum width of the surface covered by the active electrode.

If the current is increased very slowly, three or four minutes being taken in the process, the coagulation can be made to extend more deeply, and further to each side. The slow heating allows more time for the tissue, in the region where the density of the current is less, to rise to the temperature necessary for coagulation, before the tissue in actual contact with the electrode has dried. Sudden application of a strong current causes sudden intense heat in the tissue in contact and quick drying before the temperature of the deep tissues has risen.

Coagulation will extend to the depth stated above if the current is increased to its maximum in about 15 seconds.

Those who wish to practice surgical diathermy should try experimental cauterisation of blocks of raw meat. The meat is placed on the indifferent electrode and the active electrode should be placed on the surface.

Electrodes.—The *active* electrode consists of an ebonite handle, usually rod-shaped, with a metal core. Into the proximal end of the handle is screwed the cable from the diathermy machine. To the distal (free) end is attached a metal end-piece which makes contact with the tissue where the operation is being performed. The end-piece is usually a metal disc, one-eighth to one-quarter of an inch in diameter. A needle or a narrow blade are sometimes used. The selection of the end-piece depends on the nature, size and situation of the tissue to be coagulated, and further reference to this matter will be found on p. 254 *et seq*.

The *indifferent* electrode consists of a metal plate. Lead, one-sixteenth of an inch thick, and eight inches square, is a suitable size. It should not be smaller. It is placed, not in direct contact with the skin, but with a pad, composed of eight layers of lint or a folded towel of the same thickness soaked in strong salt solution, interposed. The indifferent electrode may be placed on the chest or abdomen.

Diathermic Cauterisation of Malignant Growths.—An anæsthetic is required except when very small portions of tissue have to be destroyed and the applications are momentary. A general anæsthetic is required if the tissue to be destroyed lies in a less accessible region, such as the mouth and throat, and if a large mass has to be destroyed. A local anæsthetic may be used in some cases. The electrodes are placed in position, the indifferent electrode on the chest or abdomen, the active electrode on the tissue to be destroyed. The current is then switched on and gradually increased. Bubbles of gas are seen escaping from the region of the active electrode and the tissue under the later whitens from coagulation. The current is then switched off and the electrode placed on an adjoining part. In this way the whole of the growth is coagulated. The most suitable electrode and the details of the precedure differ according to the situation of the growth, its size and condition, whether ulcerating or fungating.

MALIGNANT ULCERS.—Diathermic cauterisation has been applied to malignant ulcers of the skin, of the mucous membrane of the mouth, tongue, pharynx, larynx, œsophagus, cervix uteri, and rectum. When the ulcer can be brought into direct view, a disc-shaped end-piece is most suitable, one-eighth to one-quarter of an inch in diameter. The edges and base of the ulcer are coagulated. The coagulation should always be continued beyond the edges and below the base into healthy tissue whenever possible. The depth to which it spreads cannot, of course, be seen unless the coagulated tissue is cut or scraped away. It is not advisable to do this, because bleeding will begin when the lowermost strata are reached. It must always be the aim of the operator when performing diathermic cauterisation, to make the operation bloodless. A current which is just strong enough to coagulate the fixed tissues will not coagulate the circulating fluids, because the latter pass through and out of the path of the current before there is time to heat them sufficiently. A slightly stronger current will coagulate the slowly moving blood in the capillaries, but a considerably stronger current will be required to coagulate the more rapidly circulating blood in the arterioles and venules. In the lower parts where the current density has been just great enough to destroy tissue, there will be a region where the blood is circulating freely although the fixed tissues are coagulated. It will be evident, then, that bleeding will occur if this part is cut or scraped.

It has been mentioned that coagulation will spread as deeply as the width of the surface of contact of the active electrode. If it is thought that the growth extends more deeply, an end-piece of larger diameter must be selected. Or a disc bearing spikes may be used. The operator must proceed with great caution when he wishes to coagulate tissues in the neighbourhood of *arteries* or *bone*. From what has just been said, it will be realised that the wall of an artery can be coagulated and not the blood within it. If this be done, bleeding is not likely to occur immediately, but when the destroyed tissue is sloughing away, severe hæmorrhage may take place. If it is suspected that malignant tissue has extended to or beyond an artery, the safest plan is to ligature the vessel before the diathermy is performed.

If the malignant growth extends down to bone and an effort is made to coagulate it completely, the periosteum and bone may easily be destroyed. If this happens, healing will not take place until the dead bone has separated (even though the growth has been completely eradicated); suppuration is likely to occur and much pain and distress will be the result. Should dead bone be discovered after the slough has separated it should be removed.

FUNGATING GROWTHS.—If the growth is large and fungating, the best plan, in the author's experience, is to make both electrodes active and place them on opposite sides of the growth. End-pieces of large diameter can be used and strong currents applied until the whole of the growth above the surface, and its blood-vessels, have been coagulated. The coagulated part can then be cut away and the remaining part treated in the way described above.

There is another method of coagulating growths or ulcers by diathermy. A metal end-piece shaped like a scalpel blade, one to one and a half inches long and one-eighth of an inch wide, is used. The free end is placed in the healthy tissue a little beyond the advancing edge of the growth, the current is switched on, and as coagulation begins, the end of the electrode is pushed gradually deeper. The blade is slowly advanced round the edge of the growth, its progress always being preceded by coagulation which occurs in front of it. In this way the malignant mass is gradually freed and raised from its bed, and is finally removed from a bloodless cavity with coagulated walls. This method is suitable only for growths that are freely movable over the underlying tissue.

COMPLICATIONS.—*Hæmorrhage* is a possible complication. The reason why it may occur has already been explained. The period of the separation of the slough is the time when it may occur. Sloughs should never be forcibly separated, but should be allowed to come away spontaneously. As already mentioned, arteries should be ligatured if it is feared that the growth has extended to or around them.

Destruction of Bone.—If bone has been destroyed by the diathermic current, it will be seen or felt after the slough has separated. The dead bone should be cut away and removed.

Suppuration in the region of the cauterised parts or in the lymphatic glands draining the part seems to be a rare occurrence. The author has seen two cases only.

Broncho-Pneumonia is an occasional complication when growths of the tongue, buccal mucous membrane, pharynx or larynx have been treated by the diathermic cautery.

RESULTS OF DIATHERMIC CAUTERISATION OF MALIGNANT GROWTHS.—*Immediate.*—The coagulated tissue is made very hot, and the adjoining parts swell and become œdematous during the operation, especially when the growth is situated on a mucous membrane. Exudation of lymph begins and may last for twenty-four hours. Shock does not occur after the operation, and the patient is generally able to get up on the second or third day and leave hospital after a week. The coagulated tissue sloughs away and the cavity very quickly fills with granulation tissue. A feature of special interest is the absence of adhesions at later periods with parts in contact.

Later Results.—Almost all the cases of malignant disease which have been treated by the author by the diathermic cautery, and those which have come under his observation, treated by the same method, have been surgically inoperable. Many of these have been made to disappear, and although recurrence usually takes place, this event has in many cases been postponed for a year or even longer. One patient with an inoperable growth of the tonsil and fauces lived as long as two years and nine months after the first application of diathermy. It is always necessary to keep the cases under observation and reapply the diathermy when recurrence is noticed. The patient referred to had six applications. Other cases showed recurrence at an earlier date, but considerable improvement was the rule, and the relief from distressing symptoms, such as pain, discharge and constant expectoration (when the growth had involved the mucous membrane of the mouth and throat), nearly always occurred.

Diathermic Cauterisation of Innocent Growths.—Cauterisation by the diathermy current is an excellent method of treatment of some kinds of innocent growth, and the results are all that can be desired. The growths for which it has been found most suitable will now be mentioned together with a brief description of the methods of applying the current.

PAPILLOMATA OF THE BLADDER.—*Diathermic* cauterisation would appear to be *the* method of treatment, *par excellence,* of these growths. An irrigating cystoscope, of the type used when the ureter is to be catheterised, is required. The electrode is a flexible wire, insulated by gum-elastic except at its free distal end, which terminates in a small narrow platinum button. The button, only, is uninsulated. This electrode is placed in the side channel of the cystoscope intended for the ureter catheter.

The bladder is first washed out, then distended with water. The operator then illuminates the cystoscope lamp, brings a papilloma into view and then passes the electrode, manipulating its free end so as to bring it into contact, whenever possible, with the base of the growth. When in position, the current is switched on and increased till the tissue whitens from coagulation. Other papillomata, if present, are treated in the same way. As soon as the contents of the bladder become turbid, irrigation is again required. If the papilloma is bent so as to overly its base, it must be destroyed, by the diathermy, piece by piece, till the base comes into view, which can then be coagulated.

Diathermy of the bladder can be performed without a general anæsthetic; the urethra is cocainised before passing the cystoscope.

PAPILLOMATA OF THE SKIN AND MUCOUS MEMBRANES.—Papillomata of the skin and the mucous membranes of parts more accessible than the bladder, such as the mouth, tongue, pharynx, larynx, can be treated by diathermy. An electrode with a needle end-piece is suitable. If the growth is sessile the needle should be passed into its free end down to its base. The current is switched on and increased till the tissue around the needle whitens. Coagulation extends around the needle, so that the latter is surrounded with a sheath of coagulated tissue. If the growth is pedunculated, the stalk should be transfixed with the needle in different directions at the level of the skin. The growths should not be removed after the diathermy, but left to slough away spontaneously. For the diathermy a local anæsthetic may be required, but some patients can tolerate it without anæsthesia. By using a fine point end-piece and coagulating the growth in small pieces at a time, much less pain is caused than by using a blunt or probe-point end-piece and coagulating the tissue in larger portions or *en masse* at one application.

There is an alternative method of treating papillomata and other innocent growths. Sparks from a diathermy apparatus are used. It is described at the end of the present chapter.

NÆVI.—Nævi of the mucous membranes which cannot be treated by other methods can often be made to disappear by diathermy. Electrodes with disc end-pieces can be used for large nævi of the tongue and mucous membranes. When the nævus occupies a large part of the lip, it is safer to use the needle end-piece and transfix the nævus in different directions by way of the mucous surface, keeping the needle parallel with the skin surface. If larger surface end-pieces are used there is a risk of damaging the skin.

Cavernous nævi under the skin can also be treated by diathermy, but there is great difficulty in preventing destruction of the overlying skin. Electrolysis is a safer method. Needle end-pieces thickly insulated with a material that is durable and will not come off cannot at present be obtained. If such needles were used and passed through the skin, the nævus could be destroyed, probably without damaging the skin.

Cauterisation by Sparks from the Diathermy Apparatus.—If a patient is connected to one pole of the diathermy machine and an electrode with a pointed end-piece attached to the other pole, a stream of sparks can be directed on to any tissue requiring cauterisation, by bringing the point close to the skin without actually touching it. The tissue on which the sparks fall is shrivelled by the heat and destroyed. The destruction is superficial, but as the tissue dries it shrinks so that it can be destroyed for a few millimetres below the surface, especially if the sparks are made gradually longer. When the patient is placed in series in the circuit in the manner described, the sparks, especially if not very short, are too hot to be tolerated and strong contraction of the underlying muscles is provoked. A method of applying the sparks, described by Turrell, causes little or no discomfort to the patient. The patient is placed on a condenser couch. One like that shown in Fig. 59 is suitable. He grasps a handle connected to one pole of the diathermy machine, while the other pole is connected to the metal plates under the couch. An earthed electrode is now brought close to the skin, when sparks will pass. These sparks are very suitable for cauterisation. This method is very suitable for destroying moles, flat warts, telangiectases, port-wine marks, capillary nævi, etc.

This method is an adaption of a similar form of treatment in which the original high-frequency apparatus and condenser couch are used. The treatment is known as " fulguration." The treatment is, strictly speaking, not diathermy, because the current has to pass in the form of sparks across an air-gap of high resistance, and its strength greatly reduced. The cauterisation of the tissue is due to the intense heat of the sparks. As the tissue dries on the surface the sparks pass through it and cauterise the deeper layers.

For further information on Diathermy, see " Diathermy: its Production, and Uses in Medicine and Surgery," by E. P. Cumberbatch. Published by William Heinemann.

CHAPTER XIII

THE USE OF STATIC ELECTRICITY

Apparatus required.—The first requirement is a generator of static electricity, or, as it is called, a "static machine." The old frictional generator has been long discarded and its place has been taken by the so-called "influence machines." There are two principle kinds, the Holtz machine (and its modifications) and the Wimshurst machine.

The Holtz machine is very popular in America, where static electricity is widely used. Most workers in this country who use the static machine, prefer the Holtz type.

The Wimshurst Machine is self-exciting and the current which it produces has no tendency to reverse during action. With this machine one can never be sure beforehand which pole will be positive and which one negative, but once started the polarity will not change during the continuance of the run. It is not so sensitive to changes of the weather. In very damp weather, if it is not enclosed in an air-tight case, its output will be reduced and it will not be self-exciting. Fig. 60 shows a small Wimshurst.

It consists, in its simplest form, of two circular glass plates, each mounted on the end of a hollow boss of wood upon which a groove is turned to act as a pulley for driving the plate. The wooden bosses with the plates are mounted on a horizontal steel shaft, so that the plates are facing each other and about one-eighth of an inch apart. Directly below the plates is another horizontal shaft, upon which are secured two large wooden pulleys exactly opposite the grooves turned on the wooden bosses. A handle is provided at one end of the lower shaft, and two leather belts, one of which is crossed, are fitted round each pulley and its corresponding boss. When the handle is turned the plates will revolve in opposite directions. The plates are well varnished, and, attached to their outer surfaces are a number of radial sectors of tin-foil or thin brass.

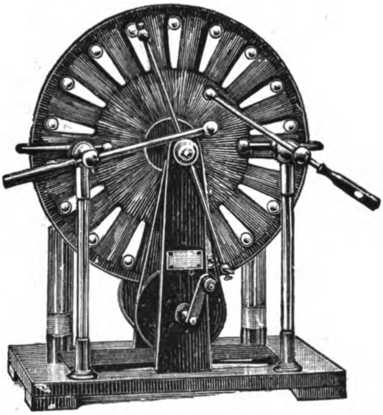


FIG. 60.—Wimshurst Machine.

These are equally spaced all round the discs. They make the machine more easily self-exciting, but are not essential to its action, especially in the case of larger machines. By means of a neutralising rod tipped with a fine wire or tinsel brush at each end, mounted so as to be adjustable concentrically with the shaft upon which the plates revolve, each pair of sectors at opposite ends of a diameter are placed momentarily in metallic contact twice during each revolution. These neutralising rods must be adjustable to the point of maximum efficiency, which will be readily found by experiment. If we stand facing the plate, and its direction of rotation be clockwise, the neutralising rod will be in the position of the hands of the clock indicating *five minutes to five*. This will vary in different machines, but the correct position will be found very near this point. The fixed conductors are mounted at the ends of the horizontal diameter and consist of two forks, with collecting points on the inside, pointing towards each other, and the plates revolving between. These forks are mounted on ebonite or glass pillars, and to each fork is attached an electrode consisting of a metal rod bearing a brass ball at one end and an ebonite handle at the other. The electrodes are movable, and an operator can grasp the insulating handles and move the electrodes, so that the brass balls can be brought closer together or farther apart. The collecting device with the discharging apparatus is sometimes called the "prime conductor." When the plates are revolved, positive electricity collects on one electrode, negative on the other. If the electrodes are sufficiently close together a succession of fine crackling sparks passes across the intervening gap. With a large machine the sparks may be many inches long. The difference of potential between the charges on the two electrodes reaches a very high value.

As usually supplied, the machines have a Leyden jar attached to each electrode, the latter being connected to the inner coating of the jar. When their outer coatings are connected together and the machine set in action the character of the discharge is completely altered. Instead of the soft crackling brush, the discharge takes place at definite intervals and each is accompanied by a more or less loud report.

The Leyden jar greatly increases the capacity of each electrode, so that they can take much larger charges, but a longer time elapses before these larger charges reach a potential sufficiently high to overcome the resistance of the air between them. A loud, intensely white, thick spark accompanies the discharge.

A shock from a large machine with the jars connected might be fatal. The jars are used only in the application of the current known as the "static induced" current. In other applications, they are disconnected.

There are made by some manufacturers various modifications of the Wimshurst. One has ebonite plates, and, on account of the toughness and flexibility of the material, the plates can be driven at a very high speed. The advantage of high speed is that the same difference of potential can be obtained with smaller plates, making the machine less bulky. The disadvantages of ebonite are that it often becomes bent and buckled out of shape. Also its insulating properties become very much impaired after a time, and the output of the machine correspondingly reduced.

For medical purposes the Wimshurst machine should have not less than eight plates, thirty or thirty-six inches in diameter. The machine should be enclosed in an air-tight case with glass windows, so as to prevent the attraction of particles of soot and dust from the atmosphere. The air inside the case can be dried by desiccators, such as boxes of quicklime or trays of sulphuric acid. The machine is driven by a small electric motor, or a gas or oil engine.

Glass, coated with shellac is at present the most suitable material for the plates. Ebonite deteriorates after a time, as chemical changes take place on its surface and impair its insulating properties. It loses its black colour and acquires a greenish tint. These changes occur more quickly if the plates are enclosed in a case. Machines with ebonite plates are not enclosed, for this reason, but soot and dust are then collected from the atmosphere. Further it tends to warp, so that the plates come in contact as they revolve.

The Wimshurst machine has the following advantages. As soon as the plates begin to revolve it begins to generate electricity. The other type of machine will not generate electricity when the plates are made to revolve, unless an initial charge has been given to it first. The Wimshurst machine is less sensitive to damp than the others.

The Holtz Machine.—In its simplest form this machine (Fig. 61) consists of two vertical glass plates, one of which (*A*) is fixed, while the other (*B*) can revolve parallel to it. The plates are close together, but do not touch. The fixed plate is slightly larger than the revolving plate. In the fixed plate are cut two "windows" (*a* and *b*) diametrically opposite each other. Two pieces of paper, known as "field plates," are fastened on to the fixed glass plate, one (*d*) being placed above the window (*b*), the other being placed below the window (*a*). A strip of paper attached to each of these field plates projects through the window on the same side and points at the revolving plate without touching it. The latter plate revolves in a direction opposite to that in which the strips point. Two metal rods (*g* and *i*), bearing metal spikes, collect the electric charges from the revolving plate on to the metal balls shown in the figure. Two of these balls, mounted on the ends of brass rods with insulating handles, are movable, and can be brought closer together or farther apart. They are made to touch when the machine is to be started. The rod *tv*, known as the "neutralising rod," carries a comb at each end, the points of which are directed towards the front of the revolving plate.

To start the machine, an electric charge from a rubbed ebonite rod is given to one of the field plates.

The movable plate is then revolved and the balls drawn apart. Sparks then dart across the gap separating them.

The modern form has six or eight plates, arranged in pairs, each pair consisting of one fixed and one revolving plate. It is enclosed in an air-tight case and is driven by a motor like the Wimshurst machine. An initial charge of electricity must be administered to one of the field plates of the Holtz machine before the plates are made to revolve, otherwise no electricity will be generated. A very small Wimshurst machine is usually placed in the case to generate this initial charge.

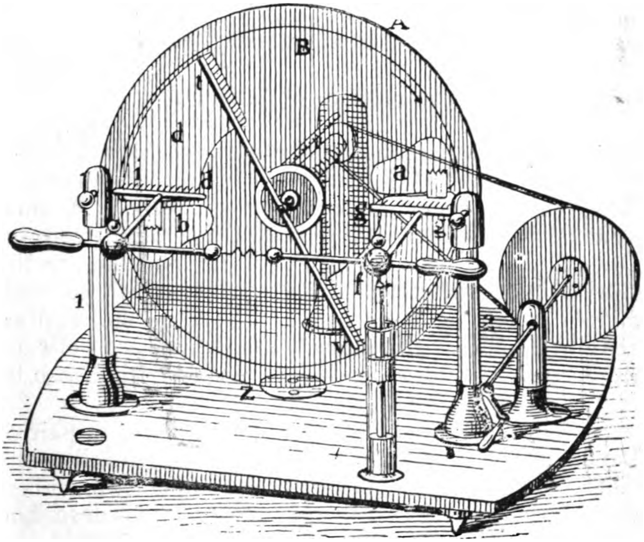


Fig. 61.—Holtz Machine (from *Electrical Influence Machines*, by J. Gray).

The Toepler machine (known also as the Voss machine) works on the same principle as the Holtz; it is usually self-starting, requiring no initial charge.

The Baker paper-disc machine is much used in America, and those who have used it in this country speak favourably of it. It is a modified Toepler machine. The stationary plates, four in number, are made of glass. The four revolving plates are made of paper. Each plate is composed of twenty-four discs of paper saturated in shellac and other gums, compressed together between hot metal discs. These plates are light, unbreakable, and do not readily condense moisture on their surfaces, and so their insulating properties are not impaired. They can be rotated 2000 times per minute. The usual rate with glass plates is 350 per minute. The machine is enclosed in a case and driven by a motor. It requires an initial charge before it generates further quantities. A small Wimshurst machine is provided for the purpose. Outside the case enclosing the static machine are the two prime conductors. The latter are fitted with sliding rods, bearing a brass ball at one end and an ebonite handle at the other. The air space between the brass balls is the spark-gap, and its length can be regulated by the sliding rods.

Static machines are usually provided with a pair of Leyden jars. One can be connected with each prime conductor. The principle on which influence machines work is that of the "electrophorus." This is described on p. 344.

Accessory Apparatus.—The accessory apparatus includes an insulating platform, a set of electrodes, lengths of brass chain for connecting the electrodes to the prime conductors or to other parts where necessary, and a long brass rod bent to a hook at one end, like a shepherd's crook, for the purpose of connecting the patient to the machine.

The insulating platform supports the patient. It is mounted on four stout glass legs. The legs should be coated with shellac to prevent the condensation of moisture on them, which would impair their insulating power. They should be at least ten inches long. When powerful machines are used, the platform should be raised thirteen inches off the ground by its insulating legs. The wooden framework should have all corners and edges rounded off. The platform should be large and strong enough to support the heaviest patient. It should measure 5 feet by 2 feet 4 inches. The patient sits on a chair on the platform. The chair should contain no metal, and all edges should be rounded off.

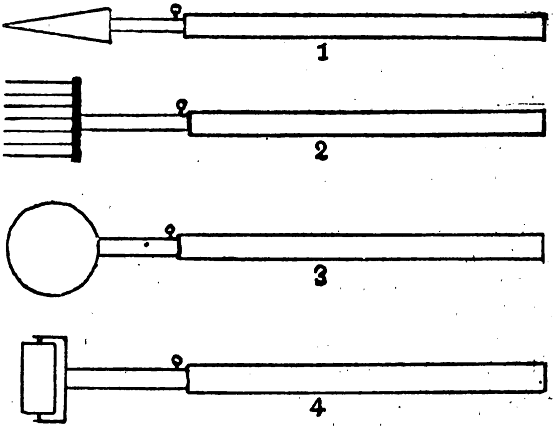


FIG. 62.—Electrodes for use with Static Machine.

1. Single-point (metal) electrode.
2. Multiple-point (metal) electrode.
3. Metal ball electrode.
4. Roller electrode.

The patient must sometimes be in a reclining position. When this is necessary, the chair should be replaced by a wicker couch.

Four common types of *electrode* are shown in Fig. 62. Each consists of an ebonite handle with a metal end-piece. The latter may be a metal rod, tapering to a point, or it may terminate in a metal disc bearing a number of metal spikes. These are known as the single-point and multiple-point electrode respectively. The metal may terminate in a brass ball (ball-electrode) or may carry a metal roller (roller electrode). The metal portion of each electrode bears a small metal ring, to which may be attached the brass chain connecting it to the machine.

These electrodes have been modified in various ways. One of these, which is particularly suitable for administering the " static breeze," is composed of an ebonite tube filled with asbestos. A metal point is attached to one end and a hook or ring at the other. The metal portions make contact with the asbestos.

The Machine in Action.—When the motor is started and the plates are revolving, positive electricity collects on one prime conductor, negative on the other. When the sliding rods are drawn a little apart, a torrent of thick white sparks bridges the gap. When the gap is made wider, the sparks become thinner and paler and less straight. When the gap exceeds a certain width, sparks do not pass, but the charges on the prime conductors neutralise each other by leaking off the prime conductors through the atmosphere. The larger the size of the plate, the longer the spark. Increase of the number of the plate increases the thickness of the spark and the strength of the current. Although the electromotive force produced by the modern static machine may reach an extremely high value, half a million volts or more, the strength of the current produced is extremely small, not exceeding a fraction of a milliampere.

When the machine is examined, while working, in the dark, or in a dim light, it will be seen that the collecting combs present a different appearance on the two sides of the machine. On one side, the points of the comb are studded with minute stars of blue light. The electricity which collects on the discharging rod on this side is positive. On the other side, blue brushes can be seen between the points of the collecting combs and the revolving plates. On this side, negative electricity accumulates on the discharging rod.

Testing the Polarity.—It is necessary to know the prime conductor on which the positive and on which the negative electricity accumulates, because each time the machine is started the same prime conductor does not invariably charge up the same. If the light is too bright to discern the appearance of the collecting combs, a convenient way to "test the polarity," as it is called, is to proceed as follows. Start the machine and bring the single metal point electrode gradually nearer to one or other of the prime conductors. The point electrode should be connected to earth by a chain attached to the ring on the metal part of the electrode and at the other end to a water or gas pipe or the floor of the room if of wood or stone. Gradually bring the point of the electrode nearer and nearer, and, as it approaches the positive prime conductor a minute star of light will appear on the point, even at a distance of several inches, and this star of light will remain without much alteration until the point is brought up almost in contact with the knob; then small sparks pass. If approached to the negative prime conductor in the same way, the discharge takes the form of a visible brush of non-luminous noiseless sparks when the point is still at a distance of two or three inches from the knob. It is easy if the light is subdued, to recognise these differences in the discharge to the point, and from them to know which prime conductor is positive and which is negatime. The differences are more evident if one of the prime conductors is earthed.

Static electricity means, literally, electricity "at rest." It is, however, only at rest when it is on the prime conductor and not leaking off. When it is applied to the body it flows on to and off from the latter. The body is alternately charged and discharged in some of the applications, so that static electricity becomes "current electricity."

The Methods of Applying Static Electricity to the Patient.—The Static Bath.—In this method of application the patient is merely charged with electricity. He sits on a chair or reclines on the couch on the insulated platform. The chair should contain no metal. The patient is connected to the positive prime conductor of the machine by means of the metal rod with the crook at the end. The end is hooked over the sliding rod of the positive conductor, while the other end is placed on the floor of the insulated platform, not in contact with the patient. The patient and the insulating stool should be at least two feet away from the machine or from the walls and other objects. Before connecting the platform with the machine, the latter should be set in action and the polarity tested. The sliding rods are then placed in contact, and the platform is connected to the positive prime conductor. The sliding rods are then drawn as far apart as possible. The patient is charged positively, and when the voltage of this charge reaches a sufficient height the electricity leaks off from the surface of the body. The sensation is agreeable, and the skin feels as if it were in contact with cobwebs. For a stronger effect, or if the machine is not powerful, the end of the crook should be placed on a sheet of metal on the platform and two of the legs of the chair should rest on it. When powerful machines are not available, the patient should be directly connected to the prime conductor by means of a light chain held in the hand or secured to the wrist. The machine should not be started until the patient is connected and the sliding rods drawn fully apart. If the patient is connected to the prime conductor after the machine has started (the rods having been placed

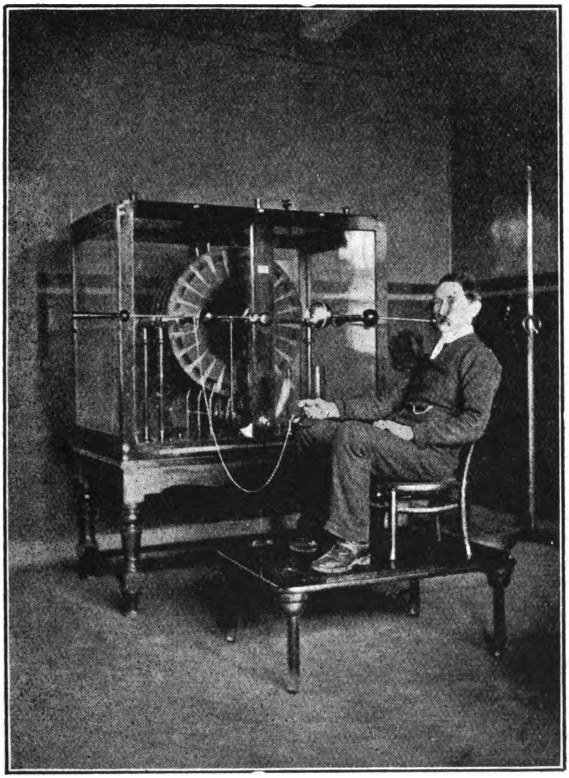


FIG. 63.—Static Bath.

in contact), separation of the rods will cause sparks to pass between them until the gap is too wide. While the sparks pass the patient will feel strong shocks, This, with nervous patients, must be avoided at all costs.

Treatment may be continued from fifteen minutes to half an hour. It is the mildest form of static electrical treatment and it produces no unpleasant sensations. It is indicated for hypersensitive, nervous patients for the production of tonic effects.

Its beneficial effects are possibly due to gentle stimulation of the sensory nerves of the skin, caused by the continuous leakage of the charge from the surface of the body. It is said that if the patient is connected to the *negative* prime conductor, sedative effects are produced.

Another method of giving the static bath is to charge the patient positively as before, and then bring the negative sliding rod gradually nearer to the positive till a spark passes; at this moment the patient is discharged, but is quickly recharged and again discharged, and so on. A stream of sparks passes between the balls on the end of the sliding rods. The rate at which the sparks follow each other depends upon the width of the spark-gap and the rate at which the electricity is generated. The width of the gap should be adjusted so that the sparks pass apparently continuously. The patient should recline on the couch on the insulating platform and the metal crook placed over the prime conductor, its other end on the platform or against a leg of the couch.

This modified method is rather more vigorous than that of simple charging. It is known as the method of "potential alternation" or "interrupted electrification." The sparks cause a continuous noise that is disagreeable to some patients.

The Static Wave Current.—This is known also as the "Morton wave current." To apply it, the patient rests on a chair or couch on the insulating platform. An electrode made of pliable sheet metal, cut to the desired shape, is applied to the part requiring treatment and connected to the positive prime conductor of the machine by means of a wire. The negative prime conductor is earthed by means of a brass chain connected to a water or gas pipe or radiator, or to a wooden or stone floor. The arrangement is shown diagrammatically in Fig. 64. The machine is started and the negative sliding rod is gradually separated from the positive. Sparks at once bridge the gap. With each spark there is a contraction of the muscles of the part under the electrode. If the sparks follow each other with sufficient rapidity the muscles are tetanised. If the sliding rods are further separated the sparks pass with less rapidity, but the contractions become stronger. It is therefore advisable to have some device whereby the frequency of the sparks may

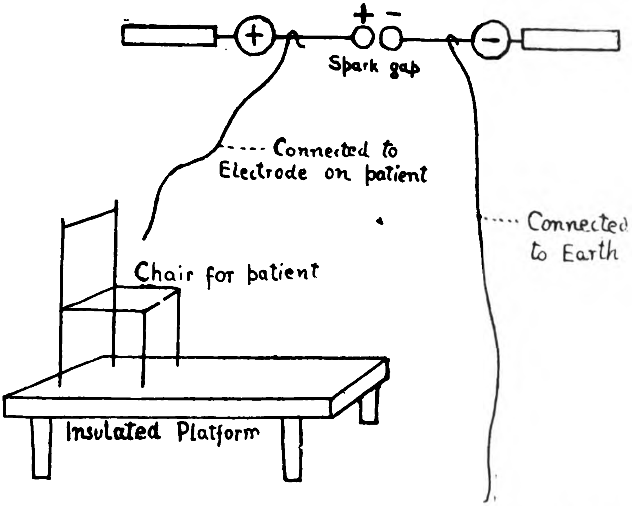


FIG. 64.—Arrangement of Apparatus for application of Static Wave Current.

be regulated. To some static machines is fitted a device called the "Baker field regulator." It is fitted to the Baker paper-disc machine and controls the frequency of the sparking. Such control is necessary for the successful application of the static wave current. The gap should be widened till the contraction with each spark is as strong as can be comfortably borne. The field regulator is then adjusted so as to give about three sparks per second.

If there is no field regulator attached to the machine the frequency of the sparks may be lowered by placing a chair close to the insulated platform adjusting the distance till the frequency of the sparking reaches the desired rate. Another way is for the operator to bring an earthed single-point electrode to a suitable distance from the platform. The most effective electrode for this purpose is the ebonite tube filled with asbestos.

The electrode should make uniform contact, and if the skin is dry it should be moistened with soap and water. The static wave current can be applied to the rectum, uterus and prostate. Special electrodes have been designed for these parts. They are made of metal bulbs with ebonite insulating handles. A terminal is fixed on the handle and is brought into electrical connection with the metal bulb by a wire along the axis of the handle. The handle should be sufficiently long so that the patient's hand is out of reach of the terminal. The bulb is passed into the rectum and the handle remains outside and held by the patient in the correct position. If the uterus is to be treated, the electrode should be held so that the metal bulb is in apposition with it through the rectal wall. If the prostate is to be treated, the metal bulb is hollowed out partially, so as to make a better apposition with the gland through the rectal wall.

When the patient is connected to the machine in the way described for the application of the static wave current, the body is charged positively—the electricity passing on to the body by way of the electrode. At the same time, the negative charge from the other prime conductor passes to earth. When the difference of potential between the latter charge and that on the body reaches a sufficiently high value, the resistance of the air space at the spark gap is overcome, the two charges neutralise each other, a spark passes across the gap and the body is suddenly discharged. The electricity leaves the body by way of the electrode. The body is alternately charged and discharged, the discharge being sudden and brisk and the charge relatively slow. Each time that the discharge takes place the muscles under the electrode give a sudden twitch. The current is therefore a to-and-fro surging of electricity to and from the body by way of the electrode.

The static wave current has been recommended for a large number of maladies in which the morbid condition is inflammation with congestion and exudation. Good results are obtained in some cases of brachial neuritis, sciatica, and fibrositis in the lumbar region. A preliminary testing application of the painful region may be made in the following way. A testing electrode composed of an ebonite handle, 16in. long, fitted at one end with a padded metal disc, 1½in. in diameter, is held by the operator, with the disc in contact with the painful region. The disc is connected, by a chain, with the positive prime conductor. The machine should, previously, have been started, the sliding rods brought into contact and the negative conductor earthed. The rods are now separated about ½in., the operator placing his foot on the platform so as to diminish the frequency of the sparks. The testing electrode is slowly moved over the region where pain is felt. It will now be discovered, in many cases, that the rhythmic twitches produce acute pain in some regions, while in others, the sensation is that of a painless muscular tug.

If the pain can be localised to separate areas, treatment may be started with the same electrode. It is kept in position over the first tender area where the contraction has been accompanied by pain. After a succession of contractions the pain gradually disappears and the patient feels only the painless muscular tug. The other areas are treated in the same way. On the following day the length of the spark between the sliding rods can be increased, either at once, or after a few contractions with the spark gap the same width as on the previous day. If the places in which pain can be produced by the twitches are close together, or if they cover a large area, an electrode sufficiently large to include them all at the same time may be used. Increase of the size of the electrode lessens the density of the current. Large electrodes can be used if the machine is powerful.

A preliminary application of diathermy seems to increase the effect of the static wave current.

In cases of sprained knee with the synovial cavity distended, the application of the static wave current to the quadriceps will cause gradual reduction of the swelling, while the treatment is in progress. The knee should be bandaged from below upwards so as to exert pressure on the distended synovial cavity. The reduction of the fluid is due, probably, to rhythmic compression of the cavity by the contracting quadriceps. Good results have been claimed in cases of inflammatory swelling of the prostrate, dysmenorrhœa with congestion of the uterus, and in diseases of other parts in which there is congestion or stasis, with or without inflammatory adhesion.

The mode of action of the static wave current is most probably mechanical, the sudden forcible rhythmic muscular contractions aiding the local circulation and the removal of inflammatory products. Serous and fibrous adhesions are broken down.

The Static Breeze (Static Brush).—The static brush is the discharge which takes place between a conductor ending at a point and another which is of large area and bears no points. A brush discharge is seen between the collecting combs of the static machine and the revolving plates. It is also seen when testing the polarity. If a patient is placed on the insulated platform and connected to one of the prime conductors, and if a metal point electrode, connected to the other prime conductor, is brought near him, a brush discharge will pass between the point and the body. The patient will be conscious of a sensation of a wind blowing on the skin. At the same time a sound resembling a wind is heard. Hence the name "static breeze." If the light is very subdued, a minute star of light will be seen on the point of the electrode, if the patient is charged

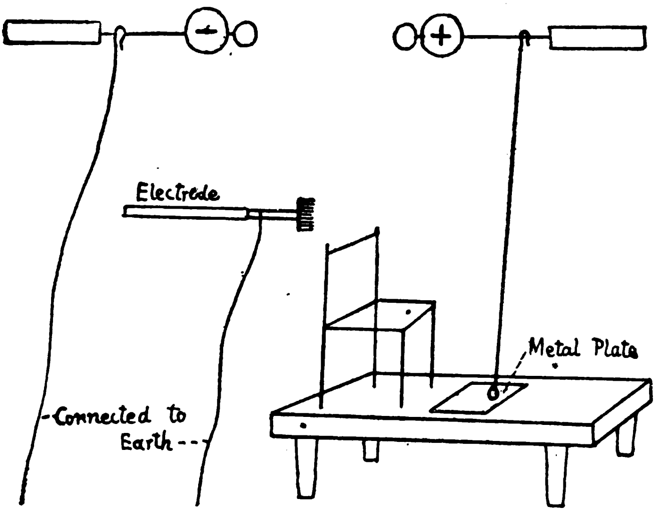


Fig. 65.—Arrangement of Apparatus for application of Static Breeze.

positively. If he is charged negatively, a faintly-luminous brush will be seen between the point and the skin. We are, in fact, proceeding as if we were testing the polarity of the patient.

When the static breeze is being applied to the patient, the passage of sparks between the point of the electrode and the skin must be avoided. When using the metal point electrodes, sparks are more likely to pass if the patient is negative. It is therefore advisable, when using these electrodes, to connect the patient to the positive prime conductor. The patient is arranged as for simple charging and connected to the positive prime conductor. The single or multiple point electrode and the negative prime conductor are connected to earth (Fig. 65). The electrode is grasped by the operator and the points are directed towards the part of the patient requiring treatment. As it approaches closer the sensation perceived by the patient loses its cool character, and when the electrode is still closer there is the feeling as of a fine spray of hot water. If the electrode is placed very near the skin, sparks may pass and cause pain. If the brush is directed on to one spot of the skin for two or three minutes without changing its position, a blister may be produced. For applying the breeze to the scalp, a light crown-shaped metal electrode is often used. It is suspended above the patient's head, either from an insulated pole or from a rod pivoted to the case of the machine. It is connected to the negative prime conductor.

If the skin is covered by a dry cloth or by the ordinary clothing, the breeze produces a still hotter sensation, which may be painful. The skin should not be damp with sweat, otherwise the breeze will lose some of its effect. If necessary, the skin may be bared and then covered by a shawl, upon which the breeze may be directed. When the distance from the body is the same, the reaction of the skin is greater when point of electrode is connected to the *positive* prime conductor. It has been mentioned that sparks will pass on to the skin sooner when the point is connected to the positive prime conductor. A strong brush discharge, therefore, cannot be obtained from a metal point electrode when the latter is connected to the positive prime conductor. If, however, we use instead of a metal electrode, one made of some material which is a bad conductor, such as asbestos, it can be brought almost into contact with the skin without the passage of sparks, even when it is connected to the positive prime conductor. It can therefore produce the strongest reaction. An electrode of this kind is preferable to the metal point electrodes.

It is thus possible, by means of the static breeze, to produce any degree of cutaneous stimulation, slight, with agreeable sensations, to a burning, tingling sensation causing pain. The stimulation of the peripheral sensory nerves causes a reflex rise of blood pressure, and it is to this that the good effect following treatment by the static breeze is chiefly due when applied for *general* effects. Patients whose pressure is abnormally high are not likely to benefit from the static breeze. Those whose symptoms (*e.g.* headache) are the result of a low pressure, are greatly benefited, and headache will often disappear during the application. The breeze, applied locally, has often a healing effect on chronic ulcers, bringing about hyperæmia, and possibly, disinfection by means of the ozone and oxides of nitrogen produced. In other skin affections, such as pruritus, eczema, acne, and psoriasis, it sometimes produces good results.

Static electrical applications, especially when the breeze is applied to the lumbar and sacral region, have a beneficial influence in cases of menstrual irregularity and amenorrhœa if no disease of the pelvic organs is present.

Electrical Sparks.—If the point electrode is replaced by the ball electrode, the discharge, between the patient and the latter, does not take place in the form of a brush, but of noisy sparks. The sensation is not pleasant and resembles that of a sudden blow. To administer sparks, the patient is arranged again as for simple charging and the ball electrode, connected to earth, is brought close enough to allow the discharge to take place. As the sparks produce an unpleasant sensation it is best to manipulate the electrode so as to allow only one spark at a time to pass. This is done by making the electrode describe a curve past the place on which it is desired that the spark should be directed, and if the manipulation is skilful and rapid the electrode is out of range before a second spark can pass.

The length of spark administered should vary according to the part to be treated, longer sparks, ten inches or more, for larger parts, such as the hip or thigh, and shorter sparks down to half an inch for smaller regions, such as the wrist or finger. The length may be diminished by slowing the rate of revolution of the plates and by using small-size ball electrodes; and the length can be further diminished if the operator places his foot close to the insulating stool. The patient should always be warned before the passage of a spark.

Treatment by means of static sparks is of value in some cases of lumbago and pain in the muscles, sometimes relieving the pain instantaneously. Probably the muscular wrench removes deep-seated congestion and breaks down adhesions. The mode of action of static sparks is therefore the same as that of the static wave current. The sparks produce a more violent effect because the current in its passage through the skin is localised to one point. When the static wave current is used, an electrode is placed on the skin and the density is thereby reduced.

A modification of the sparking method consists in the use of a roller in place of the knob. It is rolled over the *clothed* surfaces of the skin and a shower of stinging sparks passes to the patient. The thicker the layer of clothing the more intense the effect. In employing this method the operator should first place one foot on the platform before placing the roller in position, and also before removing it. In spark applications it is a good rule to always warn the patient of what is coming. Sparks from the roller cause intense sensory stimulation, with muscular contraction.

Short static sparks are useful for the discovery of tender points in the region of joints and along the course of nerves. Where the patient complains of general pain all over, an administration of sparks will frequently reveal the presence of tender spots; to these spots subsequent treatment may be specially directed.

The Static Induced Current.—This current must not be confused with the static *wave* current. Two Leyden jars are introduced into the circuit, in series with the patient (Fig. 66). The inner coats are connected one with each prime conductor. The outer coats are connected by a wire. If the machine is now started and the sliding rods drawn a short distance apart, sparks will bridge the gap. If now a gap is introduced in the circuit joining the outer coats of the jars, sparks will bridge this gap also, in synchronism with the others. If the patient is included in this circuit he will experience strong muscular contractions, with little or no pain. To apply this current to the patient the insulated platform is not required. Two electrodes are needed, of the same kind as those used for the static wave current. They are applied to the body, the sliding rods are placed in contact and the machine is started. The sliding rods are cautiously drawn apart till the muscular contraction is as strong as the patient can bear.

The static induced current has been applied with success to cases of obstinate constipation. One electrode is introduced per rectum (an electrode like that used with the static wave current may be employed). The other, a plain metal sheet, is placed on the abdominal wall. The current is started and its strength increased until it is as great as the patient can tolerate. It should be rhythmically varied between this strength and zero by alternately widening the gap and reducing it to zero.

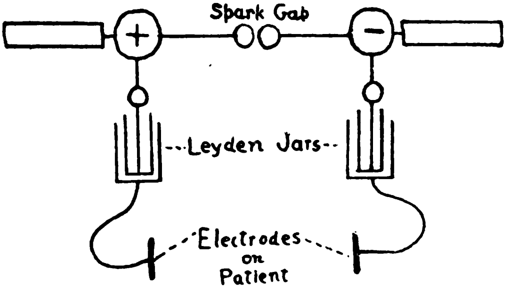


FIG. 66.—Arrangement of Apparatus for application of Static Induced Current.

CHAPTER XIV

INDEX OF ELECTRICAL TREATMENT

IN the following pages are considered the maladies and morbid conditions for which electrical treatment may be applied. In many of them, cure or relief can be obtained in the majority of cases. In others the relief is usually slight, but electrical treatment is justified in these because good results are occasionally obtained, after other methods of treatment have failed. If the best results are to be obtained the general treatment should not be brought to a close when the electrical treatment is instituted, especially in those maladies in which electricity is applied in order to treat one or more *symptoms* of the general disease. In local conditions, too, better results are frequently obtained by combining the electrical treatment with the local treatment previously prescribed.

Acne Vulgaris.—Electrical treatment is sometimes successful in cases of acne vulgaris that have proved refractory to other methods. The treatment recommended is diathermy, using a vacuum electrode and moving it over the affected area. An erythema is produced and the ozone and nitrous and nitric acids formed possibly have some disinfectant action on the infected sebaceous glands. The treatment should be repeated on alternate days and each session should last about fifteen minutes. The high-frequency machine may be used, in place of the diathermy apparatus, if the latter is not available. The vacuum electrode is connected to one end of the solenoid and the other end of the latter is connected to a metal rod which is grasped by the patient.

Ionisation with salicylic ions has been recommended, its action being probably a disinfection of the sebaceous glands.

Acroparæsthesia.—This is a condition of numbness and tingling of the hands and forearms. It may be accompanied by a weakness of the muscles in the same regions. It may be treated by application of rhythmically varying sinusoidal or faradic currents in an arm bath. Slow improvement commonly results.

Alopecia Areata.—Electrical treatment for this condition is sometimes required. Ionisation with copper or zinc should be tried first. A week later high-frequency discharges from a vacuum electrode connected to the resonator should be administered daily or on alternate days. Growth of hair in the bald patches will be produced in some cases.

Amenorrhœa.—The static breeze is very effective in restoring regularity of menstruation in cases of amenorrhœa and irregularity due to general debility. It is necessary, before applying this treatment, to exclude disease of the pelvic organs as a possible cause of the amenorrhœa. The patient is placed on the insulating platform and charged negatively, while the negative breeze is directed against the spine and lumbar region. The treatment should be repeated daily or every other day until the flow re-commences. The asbestos electrode (p. 270) should be used for applying the breeze.

Anal Fissure.—Zinc ionisation is an effective treatment for this. A zinc rod wrapped in wool soaked in zinc sulphate solution is placed in the fissure and a current of 15 milliamperes is passed for twelve minutes. After a week the fissure heals or becomes much smaller. A second application may be made, if, at the end of the second week, the fissure has not healed. If there is much pain on introducing the electrode, cocaine should be first applied. In a case treated by the author, it was found that chlorine ions caused the fissure to heal after zinc had failed. Treatment by chlorine ions causes less pain.

Aneurysm.—Electrical treatment of aneurysm has been administered in the past, the object being to cause coagulation in the sac. Electrical treatment for this purpose is no longer utilised. The method formerly used is described on p. 122.

Aphonia.—Hysterical aphonia may be treated by applying the faradic current to the larynx. An active electrode provided with a closing key and carrying a chamois-leather-covered button is applied to the front of the neck over the larynx. The indifferent electrode is placed on the back of the neck. The current is passed for short periods with intermittent periods of rest. A strong current should be used. The sudden stimulus will often cause the patient to adduct the vocal cords. The aphonia will then disappear.

Another method of treatment is to apply the static wave current to the front of the neck. Or static sparks may be administered to the same region. Static treatment has a stronger mental effect on the patient.

Arthritis.—(1) *Injuries to Joints—Sprains.*—Such cases respond well and quickly to treatment by the galvanic current. Electrodes of the type used for ionisation and described on page 95 should be used. They should be soaked in salt solution. One is applied to the joint so as to envelop it as completely as possible. It is connected to the negative pole of the source of current. The other is applied to some other part of the limb. If there is much pain and tenderness, the electrode around the joint may be connected to the positive pole. The treatment should be given daily in the acute cases (if the skin reaction following the preceding treatment has subsided), twenty minutes each session. Chronic cases may receive the treatment on alternate days. Cases of sprained knee accompanied by distension of the synovial membrane may be treated by the static wave current, in the way described on p. 278.

Joints that are stiffened by fibrous adhesions resulting from past injury can be rendered mobile by ionisation with the chlorine ion. The process is slow, but the treatment is effective. It should be applied in the way just described and repeated twice or thrice weekly for at least six weeks, and continued so long as improvement occurs. If this treatment is preceded by diathermy and followed by passive movement the improvement will be hastened.

Similar results can be obtained if the adhesions are due to old inflammation, provided that the cause responsible for the inflammation is no longer present.

(2) *Gouty Arthritis.*—Cases of *acute* gouty arthritis do not come under electrical treatment. For the chronic cases passage of the direct (galvanic) current through the joint produces good results. Ionisation with lithium has been tried but it is doubtful whether the ions penetrate far enough to be of value, and the results obtained are equally good in the absence of lithium.

(3) *Gonococcal Arthritis.*—Diathermy is a valuable method of treatment of gonococcal arthritis particularly when there is much pain. This is in accordance with the writer's experience. The rise of temperature through the joint is said to destroy the organism. Pain is quickly abolished and the joints can soon be moved without discomfort. Any stiffness which remains should be treated by chlorine ions, together with diathermy and passive movements, as described under *Injuries to Joints*.

In very chronic cases, the same treatment should be adopted; if much fibrous tissue has formed around the joint, the regain of mobility will be very slow. In some of these cases, the galvanic current is more effective in relieving the pain than diathermy. Whichever current is applied, the electrodes should be placed on opposite aspects of the joint, taking care that the edges of one electrode do not approach too closely to those of the other. If the edges are closer together than the centres, the peripheral parts of the joint will be more heated than the central parts. After directing the current antero-posteriorly, the electrodes should be shifted and the current directed laterally, when this is possible. The length of the complete application should be 20 minutes, and the treatment may be repeated daily or every other day. Methods of applying diathermy to the urethra of the male are being tried in the Electrical Department of St. Bartholomew's Hospital. Deep-lying parts, with vascular surroundings, such as Fallopian tubes, which cannot be directly heated to a sufficient degree, may be treated by diathermy in the following way:—The temperature of the whole body should be raised to 104 deg. F. and kept at this level for twenty minutes. This temperature produces no unpleasant symptoms. The treatment should be repeated daily when possible. Widespread infection should be treated by the same method.

(4) *Rheumatoid Arthritis.*—There is no known form of electrical treatment that is a cure for rheumatoid or osteo-arthritis. In the intervals between acute attacks some good may be done by passing the galvanic current through the joints, or by diathermy, but exacerbations are likely to occur, even during the course of treatment, if the cause responsible for the disease in any particular case (such, *e.g.*, as a septic focus) is not discovered and removed. If this can be done, electrical treatment, diathermy, or the galvanic current are of value in promoting the absorption of

effusion and the resolution of scar tissue and return of mobility.

Some cases of rheumatoid arthritis are benefited temporarily by the sinusoidal current, rhythmically varied in strength, applied in a Schnee bath or in a full-length bath.

(5). *Osteo-Arthritis* (*see under Rheumatoid Arthritis*).

Anterior Poliomyelitis (*Infantile Palsy*).—The treatment of this disease has been considered in Chapter IX. It may be summarised as follows:—When the patient is able to leave bed, full-length baths, using the rhythmically varying sinusoidal current should be given. If the upper limbs are affected, they should be supported in a longitudinal position in the line of flow of the current. The baths should be given daily, if possible, and continued until voluntary power is regained. If it seems that improvement has ceased, the treatment should nevertheless be continued for at least six months, until it is sure that no progress has been made for this period. When voluntary power is returning to the affected muscles, the latter should be stimulated to contract, the electrodes being placed on the soles or palms, and the current directed longitudinally along the limbs (see page 167). The current chosen should be one which does not, at the same time, cause the opposing muscles to contract and stretch the affected muscles. The simple interrupted current should be tried first, and if this fails, the surging galvanic current. If this fails, the joint should be fixed by a suitable splint, and if no contraction of the affected muscles is seen, treatment in the baths should be resumed. Even if the muscles can be made to contract, the bath treatment should not be discontinued, but it may be given less frequently.

If baths are not available, the current should be directed along the limbs by way of electrodes placed on the sole or palm and on the back. The latter should cover the whole back. The simple interrupted current, obtained by the reversing metronome, should be used if the muscles show the reaction of degeneration, the sinusoidal or faradic current if they show reactions of the normal type. Stretching of the affected muscles should be prevented by fixing the limb in a suitable splint. The sinusoidal current may, with advantage, be applied in addition. If the child will tolerate it, the latter current should also be applied by way of an electrode stroked rythmically over the skin of the affected limb. When voluntary power is returning, efforts should be made to cause contraction of the muscles by the methods described above.

It has been mentioned on previous occasions that the sinusoidal current does not cause contraction of muscles showing RD. Even if they show reactions of the normal type, the child will rarely tolerate a current strong enough, when applied to the whole body in a bath, to cause visible contraction. The experience, extending over many years, obtained in the Electrical Department at St. Bartholomew's Hospital, shows that electrical treatment of infantile paralysis can be successfully performed without causing the muscles to contract or visibly shorten. By electrical treatment, the afferent nerve endings in the skin are stimulated, and it is likely that the cells, from which the motor and other afferent nerves arise, are stimulated and, with these, the muscles and other organs.

Treatment should be continued as many times per week as possible, and should not be brought to a close until six months at least have passed without improvement.

Asthma.—Static electrical treatment, in the form of simple charging, combined with the application of the breeze or roller electrode to the thorax, has procured relief of dyspnœa in some cases.

Boils.—Small boils can be effectively treated by ionisation with zinc, a pad saturated in zinc sulphate solution being applied.

Carbuncles.—Leduc recommends their puncture to the base by a tenotome and the insertion into the channel of a zinc needle. This is connected to the positive pole of the source of current and a current of 30 milliamperes is applied for about thirty minutes.

Carcinoma (*see Malignant Growths*).

Cardiac Failure.—In cases of impending death, direct electrical stimulation of the heart muscle should not be attempted, as it is just as likely to cause what we wish to prevent—that is, stoppage of the heart's action. It is best to use an induction coil with a long fine secondary wire and apply the current by means of a metallic brush electrode to stimulate the skin, in the endeavour to stimulate the heart and diaphragm reflexly by way of the vasomotor and respiratory centres. The nose and upper lip are good points from which to influence respiration. If respiration has ceased, the phrenic nerves in the neck should be directly stimulated in the endeavour to cause contractions of the diaphragm. Two electrodes, each about one inch in diameter, are to be used. They are mounted on handles, and one of them is provided with a closing key. They are applied under the posterior border of the sterno-mastoid muscles, one on each side, and the circuit closed and opened at intervals of about two seconds. This has been successfully employed in chloroform poisoning.

Chilblains.—These can be very effectively treated, in arm baths or foot baths, by the rhythmically varying sinusoidal current. The faradic current is equally effective. The electrodes are placed in separate bowls of warm water, in which the hands or feet are immersed, one in each bowl. Some rhythmic variation can be produced by sliding the secondary over the primary or pulling the metal sleeve over the iron core. If the skin over the chilblain is not intact it should be covered by a waterproof cloth, such as oiled silk or thin sheet rubber.

Chorea.—Static electrical treatment was formerly applied to this disease with excellent results. The child, supported by its mother on the insulating stool, is connected to one prime conductor. The other is connected to a ball electrode and sparks are directed along the spine of the patient and the affected limbs. This method of treatment has fallen into disuse.

Colitis.—Ionisation with zinc ions has been recommended by Curtis Webb. As a result of this treatment the motions became natural in consistency and frequency, the mucus disappeared and the flatus diminished. (See page 105).

Congestion.—The good results that follow the treatment of injuries in the region of joints, accompanied by swelling and effusion of fluid (see under "Arthritis —Injuries to Joints"), illustrate the influence of the constant current on congestion. The current may well be applied as an aid in the removal of inflammatory products after the agent responsible for the inflammation has been removed or has ceased to operate; the current also aids the absorption of fluid exudations. Thus in cases of crutch palsy the treatment should include the application of the constant current to the area in the region of the pressure, where there is likely to be congestion.

Constipation.—When this is due to atony of the muscular coats of the intestine, electricity is probably the most efficient method of treatment known. Large currents and large electrodes are to be used. If the constant current is to be employed the anode is the indifferent electrode and it is placed under the lumbar enlargement of the spinal cord as the patient reclines. The kathode or active electrode is a padded metal disc about four inches in diameter. It is soaked in saline and applied with firm pressure over the abdominal wall, moving it round rather slowly from the cæcum along the course of the colon to the sigmoid flexure, where it is allowed to rest from two to five minutes, when the process is repeated.

This should be done every other day for three or four weeks. A sinusoidal current of low frequency—from one to two periods per second may be used if the constant current is ineffective. Or the constant current may be made to vary its strength rhythmically by including a rhythmic interrupter in the circuit.

Such treatment is frequently followed by gradual improvement and restoration of the normal frequency of defæcation; these results persist after the treatment is brought to a close.

In obstinate cases, one of the electrodes should be placed in the rectum, the other on the abdominal wall. The rectal electrode should be that described on page 105, for ionisation of the rectum. The rhythmically interrupted or slow sinusoidal current is used for about ten minutes. It sometimes happens that the bowel is provoked to action before this time elapses. In all cases the ordinary rules for dealing woth constipation must not be neglected—such as exercise, suitable diet, and use of laxatives until the case so far improves that the latter can be gradually reduced and finally left off.

The static wave current or static induced current should be tried in cases that resist other methods of treatment. (See pages 274 and 283).

Corns.—The opinion has been expressed by Lewis Jones that *painful* corns are the result of an infection of an ordinary callosity by some micro-organism, the callosity being, when not infected, painless. The treatment recommended is ionisation with zinc. It is necessary, however, to make some preliminary preparation of the corn before the ionisation. The tough, thickened skin is dry and will not conduct a current. A compress soaked in 1% zinc sulphate should be worn in contact with the corn for twelve hours beforehand. The thick skin will then be moistened and some ions will diffuse in and conduct the current. One application is often enough.

The patients will not always carry out the instructions to keep a moist compress in contact with the corn, and they sometimes arrive for treatment with the corn dry. If, then, an attempt is made to ionise it, no current will flow unless part of the pad comes in contact with the surrounding skin, in which case all the current will pass in that way and no ions will penetrate the corn.

An alternative method is to apply salicylic acid and collodion for a few days beforehand and then ionise with salicylic ions after the thick skin has separated.

Another method, which the author has used with success in some cases where the corn is very thick and hard, is to cut away as much as possible of the epithelium and ionise with a solution of potassium iodide (1%), containing, in solution, iodine (1%). A wall is formed, around the corn, of some material, such as plasticine or modelling wax, for the purpose of holding the solution and preventing the entry of the current by any way other than through the corn. The chamber thus formed is filled with the solution. The conducting cord (from the negative pole) is secured to the cushion on which the foot lies. A fine flexible copper wire is wound round the bare metal end of the conducting cord. The free end of the flexible wire is laid across the top of the plasticine chamber and embedded in its wall, so as to make contact with the fluid inside. Good contact between the other end of the flexible wire and the conducting cord is secured by partly turning back the rubber covering of the latter and then replacing it over the flexible copper wire and so keeping the metal surfaces in contact. The solution in the plasticine chamber may be held in place without fear of it running out by filling the latter with cotton wool before adding the fluid.

Corneal Ulcers.—Zinc ionisation is often successful in the treatment of corneal ulcers. A tuft of cotton wool soaked in a 1% solution of zinc sulphate is wound round the end of a zinc rod. The rod is connected to the conducting wire leading to the positive pole of the battery, and the free end of the tuft is placed on the ulcer, moving it slightly so as to come in contact with all parts of it. A current of 1 to 1½ milliamperes should be passed for four or five minutes. Cocaine should be applied to the eye before the treatment. One application is sufficient, if the ulcer is small, to effect a cure. If the ulcer does not heal after ten days, a second application should be made.

Zinc ions are sometimes able to heal that intractable form of corneal ulcer known as "Mooren's ulcer." This ulcer gradually spreads at the edges while the base acquires a covering of epithelium and ulceration does not continue in the latter part. The edges stain with fluorescein and it is to them that ionisation must be applied. A zinc rod, 1-16in. in diameter, with its free end rounded, is placed so that the latter touches the edge. A current of ½ milliampere is passed and the rod is moved very slowly along the edge. The duration of flow of the current should be such that each part covered by the zinc rod receives current for a quarter of a minute. After the treatment, a week should elapse and then the ulcer should again receive an application of fluorescein. Any part which stains requires further treatment. If much of the ulcer stains, the current should be slightly increased.

Corneal Opacities.—Considerable improvement in vision follows ionisation with chlorine ions. The lachrymal secretion contains sodium chloride in solution (and, therefore, chlorine ions), so if the lid is closed and the electrode, in the form of a lint pad soaked in salt solution, placed on the exterior and made the kathode, the passage of a current will cause the migration of the chlorine ions into the cornea. No anæsthetic is required. A current of 5 milliamperes may be borne, for two to four minutes. The treatment should be repeated twice weekly so long as improvement occurs.

Disorders of Digestion.—Electricity is useful in those disorders of the digestive tract which are due to loss of tone of the muscular wall. A slow sinusoidal current is most useful, one electrode being placed on the lower dorsal spine and the other over the epigastrium. It should be applied daily or at least three times a week for ten minutes. Dilatation of the stomach caused by atony of the wall has been successfully treated by this means.

Disseminated Sclerosis.—Electrical treatment is sometimes requested for this disease. It cannot be said that any form of electrical treatment is of value. Temporary improvement, which is occasionally noticed, is not likely due to any form of treatment that the patient is happening to have at the time, as such improvement often occurs even when no treatment is given. The galvanic current may be applied by way of an electrode covering the spine and connected to the negative pole: The legs should be immersed in the lower limb receptacles of the Schnee bath. These should be connected to the positive pole.

Dupuytren's Contraction.—Occasionally, though not as a rule, good results are obtained in the treatment of this condition of the palmar fascia by chlorine ions. Treatment should be continued for a month or six weeks before it can be seen whether any improvement is likely to take place.

Dysmenorrhœa.—Many cases of this condition are relieved by static electrical treatment, applied in the way recommended for amenorrhœa (q.v.) Lewis Jones recommended that the treatment should be given daily for a week or two before the onset of the period. With the commencement of the flow it should be left off and afterwards reapplied as before, prior to the onset of the next period.

Endometritis and Endocervicitis.—Sloan and other writers have obtained excellent results in the treatment of septic endometritis and endocervicitis by zinc or copper ionisation. A zinc or copper sound is introduced into the cervix (and into the body of the uterus also, if the latter is infected), and connected to the positive pole of the source of current; a current of 20 to 40 milliamperes is passed for fifteen minutes. If there is difficulty in withdrawing the sound at the end of the operation, the current, after reaching zero, should be reversed and allowed to flow in the opposite direction for a few minutes. Discharge follows for some days after the treatment and vaginal douches should be given. If it does not disappear after ten days the ionisation should be repeated. From five to ten applications are usually required. For an account of a method of ionising the cervix and uterine cavity, see pages 109 and 110.

Episcleritis.—This may be treated by ionisation with salicylate ions. A pad soaked in the solution of sodium salicylate is placed on the external aspect of the lid and a current as strong as can be comfortably borne (5 to 10 milliamperes) is passed for ten minutes.

Exophthalmic Goitre.—Cardew recommended the use of the constant current passed through the thyroid gland from the lower cervical spine to the sides of the neck. Currents from 2 to 3 milliamperes, for six minutes, to be applied three times daily. This treatment is effective in a small percentage of cases.

Fibrositis.—Ionisation with iodine or salicyclic ions is sometimes effective in relieving the pain associated with this condition. When adhesions are present and pain is caused on movement, an effective form of treatment is the static wave current. The method of applying it for location of the parts in which movement causes pain, is described on page 275. Single induction shocks seem to be equally effective. A coil, in which the interrupter breaks the circuit once or twice per second (see fig. 18) should be used. The active electrode is moved about until an area or areas are found in which the muscular tugs cause pain. After a succession of the strong muscular contractions, the accompanying pain gradually lessens and may disappear. This treatment should be applied daily or every other day.

Fissure (*see Anal Fissure*).

Fistula.—Some cases of rectal fistula successfully treated by zinc ions have been reported. Billinkin's method was to pass a zinc rod—its tip insulated by a cap of wax—into the fistula until the insulated tip reached the inner end. A current of 6 milliamperes was passed for three minutes. The process was repeated every two or three days, the zinc rod passed less far up the fistula each time. The fistula began to heal first at its inner end, and the healing process extended outwards till the whole length had healed.

Furuncle (*see Boil*).

Gouty Arthritis (*see Arthritis—Gout*).

Gonorrhœa and Infection with the Gonococcus.—Gonococcal urethritis has been successfully treated by ionisation with zinc or copper. W. J. Morton's method was to pass a sound with a brass stem, insulated, except at its free bulbous extremity, along the urethra up to the neck of the bladder. The current was then turned on and the stem was then slowly extracted, so that the ions from the bulbous end could pass into the wall of the urethra throughout its length. To one patient treated in this way one application only was given, and he remained free from infection for a year, when he then acquired it again.

Fenwick successfully treated two cases of long-standing chronic urethritis by zinc ions. A zinc rod was covered with lint and soaked in 2% zinc sulphate solution. It was inserted into the previously cleansed urethra, through a cannula, which was afterwards withdrawn. Small currents were used, 2 to 5 milliamperes.

It has already been mentioned that the gonococcus is very sensitive to heat, a rise of temperature slightly above the normal causing its destruction. Diathermy is therefore indicated in cases of infection by this organism when the invaded part can be reached by the electrode, and heated through, to a sufficient degree; 104° or 105° seems to be a sufficiently high temperature. For infection of the cervix uteri, a glass speculum should be placed in the vagina. The active electrode is a copper rod. It is inserted into the canal of the cervix. The indifferent electrode is placed on suprapubic or sacral region. The current is increased very gradually, the guide to its regulation being the patient's sensation. If in doubt, the operator should remove the electrode and place a thermometer in the cervix. Instead of the rod electrode, a metal stem terminating in a disc may be used. The latter is pressed against the cervix. The rod electrode ensures a more certain heating of the mucous membrane; the disc electrode allows more heating of the cervix as a whole. They might, with advantage, be used on alternate occasions.

Gonococcal infection of the female urethra may be treated in a similar manner. A sound is passed into the channel, and acts as the electrode.

Gonococcal orchitis and epididymitis can be treated by diathermy in the following way. A shallow cup-shaped electrode, padded with lint, is applied to the fundus of the scrotum, after moistening the lint with strong salt solution. The indifferent electrode is placed on the hypogastrium.

The methods described above are those used in the Electrical Department of St. Bartholomew's. Cases which contained gonococci in the infected regions were found, five months after the treatment was completed, to be free from the organism. This was shown by examining films and cultures, before and after the course of treatment. The permanence of the effect of diathermy in gonococcal infection is under trial.

The treatment of gonococcal infection of joints is mentioned under *arthritis*.

Hæmorrhoids (*see Piles*).

Headache.—Headache that is associated with *low* blood pressure is best treated by the static breeze applied to the scalp and spine. The headache often disappears during the first treatment, a result, most probably, of the rise of blood pressure. Headache associated with high blood pressure may be treated by general diathermy, the endeavour being to lower the pressure. For the description of the method of application see under *High Blood Pressure*.

Hemiplegia.—Cases of paralysis that are due to lesions of the upper motor neuron will benefit if the cause responsible has disappeared or is no longer active. If, however, there is late rigidity, much cannot be expected from electric treatment. The treatment is suitable for cases of hemiplegia due to cerebral hæmorrhage. It should begin a fortnight or three weeks after the hæmorrhage and be continued, three times weekly, for a month. If improvement occurs the treatment may be continued for further periods of one month each, till no further benefit is noticed. The treatment is best given in a full-length bath (rhythmic sinusoidal current) if the lower limbs are affected. The Schnee bath may be used when no full-length bath is available, and it can be used when the paralysis affects either the lower or the upper limbs.

Leduc recommends that treatment should be given to the lesion when present in the brain, by passing the constant current through it from the back of the neck (anode) to the forehead (kathode). The treatment should be given daily, or on alternate days, and for fifteen minutes, with a current of 20 milliamperes.

High Blood Pressure and Arterio-Sclerosis.—Patients suffering from arterio-sclerosis accompanied by symptoms, such as dyspnœa, cardiac pain, palpitation, headache, weakness, cramp, etc., often derive relief from application of high-frequency and diathermy. These patients usually have a raised blood-pressure. Much has been written on the use of high-frequency currents for the purpose of lowering the pressure, and different observers have obtained different results. Some have been able, in most cases, to lower the pressure; others have been unsuccessful. Some have used the original type of D'Arsonval apparatus (fig. 52): others have used machines provided with multiple spark gaps and large condensers (fig. 53) providing currents capable of yielding diathermy. There is no doubt that high-frequency currents, especially those capable of producing diathermy, relieve some of the cases. Such currents are able, in certain cases, to lower the blood-pressure, but if the elevation of the latter is *compensatory,* for the purpose of providing an adequate supply of blood to the various organs, any artificial reduction will do more harm than good. It is therefore advisable, when applying the treatment, to commence with short applications and less strong currents. If there is no improvement, the length and strength of the applications should be very gradually increased.

The currents may be applied to the patient on the condension couch (fig. 59). A metal rod electrode is grasped by the patient with both hands. The blood-pressure should be taken, before and after the treatment and kept for record, but the patient's symptoms and sensations are a better guide to the operator in the matter of dosage. Treatment for ten minutes should be given at the first visit. It may be repeated daily or every other day.

The diathermy apparatus should be used. If this is not available, the high-frequency machine shown in fig. 53 should be used.

If the cardiac symptoms are pronounced, the electrode should be placed on the precordium.

Hypertrichosis.—Superfluous hairs may be removed, if not too fine, by means of the electrical current.

A local anæsthetic should not be applied. The details of the operation are described on page 113. After each hair is removed a small zone of hyperæmia is left round each follicle and sometimes œdema. These soon disappear, and if the operation is neatly done, with a small current (not more than 2 milliamperes) and short applications, no scar will remain. If a group of hairs in close proximity is removed at one sitting, it is likely that a scar will be left. A small proportion of hairs will return, because it is not possible to ensure entire destruction of the follicle without strong currents. The hairs that return can always be treated again when they reach a sufficient size.

The operator must always warn the patient of the likelihood of the return of a small number of hairs.

Hysteria.—The most useful rôle of electricity in hysteria is for the removal of paralysis, anæsthesia and spasm (Lewis Jones). The current from the induction coil, applied by the ordinary moistened electrodes, or by the wire brush, may be used. Sparks from a static machine are effective and have an additional psychic effect. For the general hysterical condition, apart from local symptoms, the long bath with sinusoidal currents, or the static breeze, may be used.

Incontinence of Urine.—The cases of incontinence of urine for which electrical treatment may be given, with prospect of success, are those due to weakness of the sphincter, and those in which the incontinence is really an unconscious act of micturition occurring during sleep. Incontinence resulting from weakness of the sphincter occurs in female patients, and electrical treatment is usually successful. The rhythmically varied faradic current is used. One electrode is a metal sound. It is placed in the urethra without passing into the bladder. The other electrode is a padded metal plate and is placed on the spine in the lower dorsal region so as to overlie the lumbar enlargement of the spinal cord. Treatment may be given daily for periods of ten or fifteen minutes, and less frequently as improvement proceeds.

For cases of nocturnal micturition during sleep the same treatment may be given when the patient is a female. In male patients and female children one electrode is placed on the lower dorsal spine, the other on the perinæum. A special electrode is used for application to the perinæum (Fig. 67). It is composed of a wooden handle bearing an acorn-shaped metal end-piece with rounded apex. The latter is covered by chamois leather secured in position by a vulcanite ring which slides over the cone and fits tightly around its base. Stroking movements of the leather-covered end of the electrode are made over the perinæum so as to produce rhythmic stimulation. For cases of nocturnal micturition during sleep, strong applications are neces-so as to produce a strong sensory impression on the urethra, and so on the cerebral sensory centres. In this way the patient is made more strongly aware of the condition of the urethra, so that when the bladder is about to expel its contents into this channel the cerebral centre receive stronger impressions and the patient is awakened. Lewis Jones recommended the application of the galvanic current after the faradic for three or four minutes, with reversals of direction every five seconds, and of a strength of 5 to 10 milliamperes.

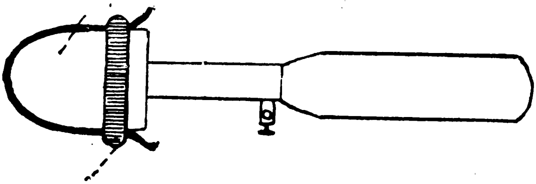


FIG. 67.—Electrode for Enuresis (seen in section).

Cases of incontinence and frequency of micturition that are due to irritability of the bladder wall do not benefit under electrical treatment if the irritability is due to inflammation of the bladder wall. The incontinence will persist until the cystitis is removed. The so-called "irritable bladder," without symptoms of cystitis, in female patients, can be treated by faradic stimulation of the urethra and bladder wall, by means of a sound passed into the bladder. The other electrode is placed, alternately, on the supra-pubic and sacral regions.

Ingrowing Eyelashes.—These can be removed by electrolysis (see under *Hypertrichosis*), but the operation is painful, on account of the sensitiveness of the part. Local anæsthesia is usually required. Many of the hairs are fine and difficult to remove.

Insomnia.—Electrical treatment is occasionally given for insomnia, in conjunction with other methods of treatment. Patients whose blood pressure is low are best treated by the static breeze ; those in whom it is high should receive general high frequency or general diathermy.

Intermittent Claudication.—Electrical treatment in a Schnee bath, with rhythmically and slowly varying faradic or galvanic currents, may be applied in these cases. Good results are obtained, but courses of treatment should be repeated periodically.

Joints, Injuries and Diseases (see under *Arthritis*).

Keratitis.—Traquair recommends the use of zinc ions for the treatment of purulent keratitis and has obtained good results by this method. He devised a special electrode for the purpose. It consist of a zinc rod with a celluloid cap at its end. The cap is filled with cotton wool soaked in ½% zinc sulphate solution. The wool is brought into contact with the eyeball and stroked over it.

Lachrymal Obstruction.—Obstruction of the canaliculi can be removed by inserting a platinum probe into the canaliculus ; an indifferent electrode is placed in some convenient situation ; a constant current, 2 to 4 milliamperes, is passed from the indifferent electrode to the platinum probe for thirty seconds. The probe is therefore the kathode. Two or three sittings are required. The obstruction is permanently removed (Jessop and Steavenson).

Locomotor Ataxy.—Some of the symptoms of this disease can be relieved by the application of the constant current to the spine. One electrode (the anode) is applied to the cervical spine, the other to the lumbar spine. The pains and unsteadiness of the gait are relieved in some cases. The same treatment is recommended for the crises—gastric, laryngeal and vesical. It is said that if it is applied during a crisis the pain is relieved in a few minutes.

Lupus Vulgaris.—Of the electrical methods of treatment of lupus vulgaris the following may be mentioned: (1) Ionisation with zinc ions. This method gives good results in cases where nodules persist after healing of ulceration by Finsen light or X-rays. The method recommended by Taylor and MacKenna is to first rub the part with liquor potassæ. This denudes the nodules of their epithelium. The liquor potassæ is washed away with water and the part of the skin containing the nodules is covered with a lint pad saturated with 2% zinc chloride solution, or 10% zinc sulphate. The current is passed for ten to thirty minutes. The ionised part gradually becomes swollen and red, and a crust forms on the surface. A fortnight after the ionisation the crust drops off and the nodules are then seen to have become smaller. Some may have disappeared. So long as any nodules remain the treatment is repeated fortnightly. A smooth elastic scar results. (2) "Reyn's electrolysis." The patient takes, by mouth, a large dose (40 to 60 gr.) of potassium iodide. An hour later the lupus nodules are transfixed with a group of platinum or iridium needles set close together on a suitable handle. A current of 3 to 4 milliamperes is passed from the needles (the anode) through the nodule to an indifferent electrode for three minutes. The needles are then taken out and reinserted in a different position and the current again passed for a similar time. The process is repeated till the nodule has been transfixed in all directions. Iodine is set free around the needles and destroys bacilli in the neighbourhood. The following events occur during the process. The potassium iodide is absorbed and passes into the tissue fluids. The latter, therefore, contain iodine ions. Those present in the lupus nodule are attracted to the needles (which form the anode). They give up their electric charge and then become free iodine.

The treatment is repeated daily until the nodule has disappeared.

No necrosis of the tissue takes place.

This method of treatment is suitable for lupus of the mucous membranes. (3) Lupus nodules and tuberculous ulcers can be treated by cauterisation with diathermy. After procuring local anæsthesia, a needle electrode is passed into the nodule or into the base and edges of the ulcer, and the current is very slowly increased. The tissue around the needle coagulates, and the whole of the nodule or ulcer can be destroyed by one or more applications. It is advisable to continue the cauterisation for a short distance into the surrounding healthy tissue. An electrode terminating in a small metal ball end-piece, two or three millimetres in diameter, is probably more effective than a needle end-piece, although it is likely the destroy more tissue.

I have treated successfully, by this method, two cases of tuberculous ulcer of the skin which proved refractory to other methods of treatment.

Malignant Growths.—Malignant tissue can be destroyed by means of zinc ions, using very strong currents and long applications, under general anæsthesia. Several applications are necessary. Betton Massey is the advocate of this method. It is described on page 122. Keating-Hart uses the sparks from powerful high-frequency apparatus. "Fulguration" is the name given to this form of treatment.

The destruction caused by "fulguration" is most probably due to heat.

The most successful method of treatment of inoperable growths is by diathermy. For particulars see page 251 *et seq.*

Menstrual Irregularities (see *Amenorrhœa* and *Dysmenorrhœa*).

Mental Diseases.—The cases most likely to benefit are those of melancholia in adolescents, and mental apathy. These are often accompanied by failure of general nutrition. In the cases reported the method employed was a course of sinusoidal baths, and the results were so good that it should be always tried. The general effects were a complete, or nearly complete, relief of mental symptoms and a progressive gain in weight. Apparently these good results were due to the improvement in general nutrition—the brain benefiting indirectly.

Meralgia Paræsthetica.—This is a painful numbness of the outer aspect of the thigh. It is due to a neuritis of the external cutaneous nerve caused by injury or pressure. Pressure by a badly fitting corset may cause it. Ionisation with salicyclic ions is a suitable form of electrical treatment.

Metatarsalgia.—I have seen good results, in three cases of metatarsalgia, follow the heating through of the feet by diathermy. One patient on whom surgical operation had been repeated, without lasting benefit, improved so much that he was able, after a course of treatment, to walk long distances without pain. Another patient was completely relieved, and the pain had not returned eight months after the completion of the treatment, although his work was of the heaviest type.

Moles.—Small hairy moles should be treated by removing the hairs, using the method described on page 113. The mole will then disappear. If there is a pigmentation of the skin some of it will disappear after the epilation. If there is much remaining pigment it can be removed by destroying the cells in which it lies by means of zinc ions. A zinc needle is inserted at several points for short distances and currents of 2 milliamperes passed for one minute for each insertion.

Moles without hair can be treated by ionising their base with zinc, using a zinc needle. The method is described under *Warts*.

Treatment by diathermic sparks is a good method and is very quick. (See page 260).

Monoplegia (see *Hemiplegia*).

Myalgia.—By this is meant muscular pain—the result of over-fatigue—a condition which is brought about very easily in debilitated persons. It is most frequent in the trunk muscles and is accompanied by local tenderness and increase of the pain on movement. It is found, most usually, at the origin or insertion of certain muscles, the most common of which are the trapezius, spinal muscles, pectoralis major and minor (inframammary pain) and rectus abdominis.

General electrical treatment, by rhythmic sinusoidal currents, in the long bath is of value in improving the condition of the body and the muscles. Local applications of the same current are useful for the treatment of the affected muscles. The constant current, without rhythmic variation, may also be tried; the anode being placed over the painful area.

Myelitis.—Electrical treatment is beneficial for the *results* of myelitis—*e.g.* weakness in the lower limbs and in the bladder and rectum—and for trophic alterations in the skin—*e.g.* bed-sores.

The constant current should be applied to the spine;

the kathode should be placed over the vertebral column in the region of the damaged spinal cord. The anode is placed on the abdomen. The application of rhythmically varied faradic or sinusoidal currents in baths is useful in improving the condition of the muscles of the limbs. Bed-sores should be treated by zinc ions. In some cases the application of the galvanic current without the entry of zinc ions is more effective. The electrode covering the ulcer should be made the kathode.

Nævus.—The method of destruction of nævi by electrolysis has been described on page 116. This method of treatment is most suitable for cavernous nævi, with or without capillary nævi in the overlying skin, for stellate veins, nævi composed of distinctly separated vessels, for nævus verrucosus, and minute capillary nævi. Large capillary nævi can be treated by electrolysis, but the process is very slow. Port wine marks can be removed by sparks from the high-frequency or diathermy apparatus (page 260).

Pulsating nævi and large nævi of the mucous membranes are best treated by the diathermic cautery. The same method has yielded good results for large cavernous nævi which could not be removed by electrolysis.

Nævi composed of a few separate distinct vessels can also be treated by diathermic sparks. The methods of treatment of nævi by diathermy are described on page 259.

Neuralgia.—It is necessary, when using the term neuralgia, to have a clear knowledge of what the term connotes. The term should be used for those cases of pain in the area of distribution of a nerve without any morbid condition of that nerve. The pain is a "referred pain," referred to the area of skin supplied by the nerve, There may be no evident exciting cause, but when one is present, it is not on the same nerve or nerve branch as that along which the pain is referred, but on another, so that the reference of the pain is a sort of reflex act, the afferent and efferent channels being sensory nerves. Thus a carious tooth may be a source of irritation of the inferior dental branch of the fifth nerve and cause a pain to be referred reflexly along the *cutaneous* branches of the trigeminal nerve. Neuralgic pains are frequently intermittent pains. Cutaneous tenderness is frequently present. A form of electrical treatment that is suitable for neuralgia (referred pains) is the application of the faradic current by means of a wire brush to the skin, so as to produce strong counter-irritation. Another method of treatment is the introduction of ions, salicylic or quinine, into the skin. These methods of treatment are occasionally successful and should be given a trial before more heroic methods are adopted. Exciting causes must be looked for and removed, if possible. Often no cause is discovered.

(1) *Trigeminal Neuralgia.*—Some cases of trigeminal neuralgia benefit greatly by introducing, into the painful area of skin, salicylic ions or quinine ions. The affected side of the face should be covered by a well-fitting pad.

(2) *Great Occipital Neuralgia.*—Neuralgia of the great occipital nerve should be treated by ionisation with salicylic or quinine ions.

Neurasthenia.—This is a term applied to a class of case which is supposed to result from exhaustion of the brain (psychasthenia) or spinal cord, the patients considering themselves mentally and physically worn out, as well as the subject of some serious organic disease. They are convinced of their own inability to discharge the "daily round," and in neglecting their usual vocation give themselves up to brooding over and magnifying their real or fancied disabilities.

In the treatment of neurasthenia we should, as far as possible, endeavour to improve the moral or mental condition of the patients by encouraging them to feel more confidence in themselves and to assure them that recovery is within their reach. In most cases it is advisable for them to give up their usual vocation for a time, which may be from three months to a year, or even more. Complete rest with change of diet and environment are very important factors in bringing about a cure.

Electrical treatment may be prescribed as part of the general conduct of a case of neurasthenia. General stimulation of the body by means of the sinusoidal current in baths is useful. The static breeze seems to benefit the general condition of the patient, probably by raising the blood pressure. Some patients derive benefit from cerebral galvanisation. The current must not be strong enough to cause excitement or restlessness. It should not exceed 5 milliamperes at the first application. The patient should rest for two or three hours after the treatment and sleep if possible. The forms of general stimulation of the nerve centre known as "general galvanisation and faradisation" may be tried (see page 142).

Neuritis.—Electrical treatment is of value for cases of neuritis. In some cases of neuritis the motor nerves are mainly affected and paralysis is the chief symptom. In others the sensory nerves are chiefly involved and pain is the chief symptom. Where paralysis without pain is the chief feature, the rhythmically varying current should be applied, the electrodes being arranged in positions so that the affected nerves and their muscles are included in the treatment. The current may be applied to the part placed in a bath. The treatment is best given in full-length baths when the neuritis is general. The details of the method of electrical treatment are described in the chapter on the treatment of paralysis.

When pain is the chief symptom of the neuritis the treatment should be applied to the tender areas. Among the electrical methods of relieving pain are diathermy, ionisation, the high-frequency effluve and the sinusoidal current. It is not easy to say precisely which is the most effective method for any one form or case of neuritis. Different cases respond better to different methods, and also the same case at different stages. Better results sometimes follow combined treatment by two methods. As a guide to the practitioner the following statements, which are based on the author's experience, may be made.

If it is found, on enquiry of the patient, that heat relieves the pain, diathermy should be applied. If tender spots can be discovered (as can be done in many cases) an active electrode, disc-shaped, 1½ inches in diameter, should be applied, in succession, to these spots. The electrode should be padded and soaked in salt solution. It should be applied for about five minutes to each spot. The indifferent electrode may be placed on a distant part of the limb. The current should be as strong as can be borne. This treatment should be repeated daily. The author has found this treatment successful in some cases in which all other methods failed to procure relief. In most cases treatment by diathermy relieves pain temporarily. When the relief is found to last a few hours only, the high-frequency effluve may be applied immediately after the diathermy for 5 to 10 minutes. When tender areas cannot be localised, a larger active electrode should be used and applied to the part where the patient feels the pain.

When diathermy is ineffective (or if no diathermy machine is available), ionisation should be the method of treatment. Iodine or salicylic ions should be tried first, and they may be applied simultaneously in the following way. Tincture of iodine is painted over the tender areas, and a pad soaked in solution of sodium salicylate is placed so as to cover them. An indifferent electrode is placed on a distant part of the limb. After the current has passed for a few minutes, the brown stain on the skin will disappear. The current should be passed for 15 or 20 minutes, and the treatment repeated on alternate days, or every day if the erythema caused by the previous application of the current has disappeared. In some cases, quinine ions are more effective than iodine or salicyclic ions. Treatment by ionisation can also be applied, when it is necessary to keep the patient in bed. Usually, it is advantageous to apply the high-frequency effluve for 5 to 10 minutes after the ionisation.

If the methods of treatment, above described, do not cure the case, or procure only partial relief, the static wave current should be applied. The method is described on page 274. Some practitioners apply this method at the commencement. In the absence of a static machine, single induction shocks may be applied. The method is described under *fibrositis*.

A useful way of exactly locating the affected areas is the following. It can sometimes demonstrate them when pressure does not cause pain. A sinusoidal current, or a faradic current which does not cause painful sensation in the skin of normal regions, is applied by means of a testing electrode. This electrode should be a metal button, $\frac{1}{8}$ inch in diameter, covered with chamois leather. It is soaked in saline and stroked over the region in which pain is felt. It will be found, in many cases, that acute pain is caused when the electrode is passed over definite spots. These can be mapped out. Sometimes they can be located in a single point.

When the stage of acute pain has passed, the sinusoidal current is a valuable method of treatment. The painful parts should be covered by closely-fitting electrodes or immersed in water when possible, and the current should not be strong enough to produce muscular contraction. If this current causes pain during or after its application, the other method should be resumed for a further period. The sinusoidal current applied to the whole body in a bath is a good method of treatment when the neuritis is due to some organic poison, even if one nerve trunk only is affected. The general treatment is likely to promote the elimination of the toxins and stimulate the self-defensive mechanism of the body.

The more commonly occurring forms of neuritis may now be mentioned.

(1) *Alcoholic Neuritis.*—Electrical treatment is not prescribed in the acute stage of this form of neuritis when there is severe pain, but when this stage has passed and the patient is left with weakened or powerless muscles, treatment in the full-length electrical bath with rhythmically varying sinusoidal or faradic currents is of value and hastens recovery.

(2) *Arsenical Neuritis.*—Neuritis may be the sequel of a single large dose of arsenic, and it arises when the violent acute symptoms that immediately follow the dose have subsided. Neuritis may also arise during the medicinal application of increasing doses of arsenic, with or without general symptoms (salivation, nausea, vomiting, etc.). Electrical treatment may be given, with benefit, when the acute stage has passed, on the lines already laid down.

(3) *Brachial Neuritis.*—This is a neuritis that involves the brachial plexus, either the whole or one or more of its trunks. It occurs after injury or exposure to cold, especially in patients who are predisposed to

it by gout, alcohol or syphilis. The latter maladies should receive appropriate treatment and electricity should be applied in the forms mentioned when there is pain. If there is weakness afterwards, rhythmic sinusoidal or faradic currents should be applied.

(4) *Rheumatic Neuritis.*—This is a clinical form of neuritis in which there is no evident cause; a history of exposure to cold and wet is sometimes obtained, but this is, most probably, a predisposing cause. Brachial neuritis is, in many cases, a "rheumatic" form of neuritis; so also is sciatica. Facial palsy is frequently the result of a "rheumatic" form of neuritis.

The form of electrical treatment is determined by the degree of pain present: diathermy or ionisation followed by effluve if there is much pain, sinusoidal currents if there is, chiefly, weakness.

(5) *Septic Neuritis.*—This is a form of neuritis that occurs in parts that are the seats of septic infection. The exciting cause is no doubt the infecting organism. It is seen in cases of bullet and shrapnel wounds that have become infected, and it sometimes occurs in parts that have been the seat of abscesses. It seems possible that toxins absorbed from septic foci may cause neuritis in parts at a distance. Lewis Jones mentioned a case in which facial paralysis, accompanied by pain and numbness on the same side of the face, followed confinement attended by sepsis.

Recovery in cases of septic neuritis is very slow.

Lewis Jones recommended the use of the constant current in the limb baths. The cases that have been sent to the writer for treatment of septic neuritis in soldiers following bullet and shrapnel wounds have derived benefit from the constant current, applied through moistened pads or in the Schnee bath.

Neuritis may occur after many of the specific fevers. General electrical treatment in baths is useful in such cases. Neuritis is liable to occur in syphilis, the poison of the latter being especially prone to attack nerve tissue. Electrical treatment should be given in conjunction with anti-syphilitic remedies. Neuritis may also occur after gonococcal infection.

Nocturnal Incontinence (see *Incontinence*).

Obesity.—Bergonié has introduced a new electrical method for the removal of superfluous fat. A faradic current is used to tetanise the limb and trunk muscles rhythmically and make them work against resistance. The current from a specially designed induction coil is taken through a mercury metronome in which it is interrupted about sixty times each minute. It is then distributed to separate pairs of electrodes, which are applied to the body and include between them different groups of muscles. The strength of current passing to each pair of electrodes is regulated by variable resistances. The resistances are mounted on a switch-board. Of the electrodes, four are metal plates fixed to a special reclining chair, two at the back, two to the seat. They are covered, each separately, with towels soaked in hot water. When the patient sits on the chair his shoulders and back are in contact with two of these electrodes, his buttocks and thighs with the other two. His legs and forearms are suitably supported on rests. Other electrodes are made of metal plates. They are applied to the forearms, abdomen, thighs and legs, with pads of moistened lint intervening, and secured in position by straps. When the apparatus is set in action the various muscle groups contract rhythmically and simultaneously, sixty times each minute. The movements of the limbs and other parts are resisted by sand-bags placed on the abdomen and fronts of legs, thighs and forearms. The total weight of these bags may reach 100 lb. or more. As a result of the large amount of work passively done by the muscles, the patient sweats profusely and gives off large quantities of heat, and excess of carbon dioxide is exhaled. The pulse-rate increases and the blood pressure falls.

Treatment should be given daily, for periods of twenty minutes at first, afterwards increasing the sessions to thirty minutes or more. A loss of weight of three to five pounds a week may be expected. A large appetite may arise as the weight diminishes and must be controlled.

Occupation Spasm (see *Writer's Cramp*).

Œsophageal Spasm.—This condition of muscular spasm of the œsophagus without organic stricture may be treated by passing the faradic or galvanic current between electrodes placed, one on the spine over the œsophagus and the other on the front of the chest.

Œsophageal Stricture (see Chapter VI., page 121).

Orchitis and Epididymitis have been successfully treated with the constant current with the electrodes placed on the front and back of the scrotum. In the acute stage, only very mild currents can be borne—½ to 1 milliampere. In the chronic stage 10 or 20 milliamperes may be employed. The electrodes may be moistened with potassium iodide solution, and then the iodine ions which migrate in from the negative electrode may have some therapeutic action. Orchitis and epididymitis caused by infection with the gonococcus should be treated by diathermy. The method is described on page 301, under *Gonococcal Infection.*

Ophthalmia Neonatorum.—A case treated by zinc ions was reported by Ramsden. A cotton-wool pad soaked in a 2% solution of zinc sulphate was placed on the front of the cornea and sclerotic. A current of 0·5 milliampere was passed for three minutes. The treatment was repeated twelve hours later. In two days the ophthalmia was cured.

Optic Neuritis.—Cases have been reported in which improvement has resulted by passing the constant current transversely from temple to temple and longitudinally between the front of the eye and the back of the head. Small currents are used—2 milliamperes.

Ovarian Neuralgia.—This may be treated by passing the constant current between the front of the abdomen where the pain is felt and the back. Large currents, ot 40 to 50 milliamperes, should be used.

Ozæna.—High-frequency treatment with a vacuum electrode introduced into the nasal cavity has been recommended and good results have been reported. Ionisation with copper ions has produced good results. The cavity on each side is packed with cotton-wool soaked in 2% copper sulphate solution, and a copper wire is embedded in the wool without touching the mucous membrane anywhere. A current as strong as can be borne by the patient without pain should be applied for fifteen minutes.

Paralysis.—The electrical treatment of paralysis is considered in Chapter IX.

Paralysis Agitans.—The writer has seen considerable improvement in five cases of the disease following general diathermy. In three patients, electrodes were grasped by the hand; in the others the treatment was applied on the diathermy condenser couch. The tremors diminished and the gait improved and there was a gain in general health. The improvement was maintained for some months after the treatment was left off, but ultimately the symptoms recurred. Treatment was given for periods of twenty to thirty minutes, twice weekly. The patients were all over 50 years of age. In younger patients the treatment seems to be of less value.

Paraplegia (see *Hemiplegia*).

Piles may be destroyed by zinc ionisation. A method was described by Bokenham (*Proc. Roy, Soc. Med.*, vol. ii., Section of Electro-therapeutics, page 135. The pile is transfixed with zinc needles previously amalgamated by dipping them for a moment, first in water, then in dilute sulphuric acid, then in mercury. The needles are connected to the positive pole. An indifferent electrode is placed under the hip, the patient lying on his side. The current is very slowly increased, till, after ten minutes, it reaches 25 milliamperes. The pile changes in colour from a red or blue-red to a yellow or grey-yellow. Then the current is diminished, with equal slowness, to zero. Before the pile is transfixed, 10% cocaine is applied on a pad, and then cocaine (5%) and adrenalin are injected. After ionising one portion there should be an interval of ten days.

An electrode, like that shown in fig. 38, may be used. The needles are inserted in different parts of the pile. If the latter is of the size of a pigeon's egg, about one half of it can be treated at one application. Ten days later, the remaining portion should be treated. The blood is coagulated by this treatment, and the pile shrinks and after a few days, falls off.

Cauterisation by diathermy is a quicker method of treatment and is very effective. After procuring local anæsthesia, an electrode terminating in a disc end-piece ¼ inch in diameter is held against the pile and the current is increased till it whitens from coagulation.

The pain and spasm caused by hæmorrhoids can be treated by diathermy. A metal rod electrode ½ inch in diameter is passed into the rectum and the current is increased until the heat is as much as can be borne, without any discomfort.

Treatment for 20 minutes may be given twice or thrice weekly.

Pleurisy.—Pleural adhesions may be treated by chlorine ions (Leduc). Large electrodes are used, placed on each side of the chest, and one should be of sufficient to cover nearly the whole of the affected side. The other should be placed on the other side. Strong currents should be applied for long sittings and frequently repeated.

Port-Wine Marks.—These may be treated by the method of surgical ionisation, described in Chapter VI., under *Nævi*. They may also be treated by sparks from the high-frequency or diathermy machine (page 260). This is a quicker method than surgical ionisation.

Prostatic Enlargement.—The static wave current has been recommended for enlargement of the prostate, but only when the enlargement is due to congestion. A special electrode is used and is placed in the rectum in apposition with the prostrate. (See page 276).

High-frequency treatment on the condenser couch with a metal electrode in the rectum has been recommended for inflammatory enlargement of the prostate. The current should be able to produce diathermy.

Pruritus of the anus and vulva may be treated successfully in some cases by the static breeze, or by the high-frequency effluve. The glass vacuum electrode may be used either with the high-frequency or the diathermy machine.

In some cases iodine ions are successful. A 2% solution of potassium iodide is used. A circular aperture is cut in a piece of waterproof cloth and applied to the skin between the buttocks, so that only the affected part around the anus is exposed. A lint pad soaked in the solution may then be applied over the aperture. In this way iodine ions will gain entry only into the part desired.

Pyorrhœa Alveolaris.—This may be treated by zinc ions. A zinc needle with a thin layer of wool wrapped round it, soaked in 2% zinc sulphate solution, is insinuated between the gum and the root of the tooth. Only a very small current can be borne, ½ to 1 milliampere. On subsequent applications it may be strengthened. The current is passed from a half to one minute. The current must be increased very gradually and evenly, on account of the tenderness of the part. When the current is derived from a portable battery of cells a shunt resistance must be used, so that the current that is to be applied to the teeth can be gradually and evenly regulated.

Raynaud's Disease.—This is best treated by passing the galvanic current between the spinal cord (cervical enlargement if upper extremities are affected, lumbar enlargement if lower extremities are affected) and the hands or feet. The current should not exceed 25 milliamperes. The electrode over the spinal cord is made the kathode, while the hands or feet, immersed in water, are connected to the positive pole. The current should flow for 15 to 20 minutes. This treatment seems to lessen the frequency of the paroxysms and to increase the comfort of th patient between the attacks.

Rectal Fistula (see *Fistula*).

Rheumatoid Arthritis (see *Arthritis*).

Rickets.—Children suffering from rickets are not usually sent for electrical treatment, but improvement quickly follows the general stimulation of the body provided by the rhythmic sinusoidal current in the electric bath. Lewis Jones spoke highly of this method of treatment.

Rodent Ulcer.—This may be treated by ionisation with zinc ions, and the method is more particularly indicated in the early cases. The surface of the ulcer is cleaned with a 2% solution of zinc sulphate after removing any crusts or discharge. A pad of lint, cut to fit the ulcer and slightly overlapping its edges, is applied to it. A zinc disc, bearing a terminal for the conducting wire, is pressed against the pad. The current is passed for fifteen minutes. It is very gradually increased till it is as strong as the patient can bear. The tissue underlying the pad becomes pearly white. The treatment need not be repeated till fourteen days have elapsed, and only if the ulcer does not begin to heal.

For ulcers that have developed again after they have healed under former treatment, diathermic cauterisation is rcommended. The writer has seen cases of rodent ulcer that proved to be intractable to all other methods of treatment heal under the influence of the diathermic cautery. One case was treated nearly seven years ago and no recurrence has taken place.

Cauterisation by diathermy is the only method of treatment likely to be effective when cartilage or bone have been invaded. For details of the method see Chapter XII., under *Surgical Diathermy*.

Sarcoma (see *Malignant Growths*).

Scars.—The scar tissue that is formed after chronic inflammatory processes can be softened and rendered less tense by ionisation with chlorine ions, provided the cause responsible for it is no longer present. The writer has seen the cicatricial contraction, that followed a Halsted operation and prevented abduction of the arm, disappear after twelve sessions of ionisation with chlorine ions, and full-range movement of the arm return. After destruction of tissue—*e.g.* by burns or gun-shot wounds—the scar tissue that forms can be rendered soft and supple. Good cosmetic results follow treatment of scars due to burns by this method. It is necessary to be patient. If treatment is given thrice or twice weekly, six or eight weeks must not be considered a long period.

If the electrical treatment is preceded by massage or diathermy and followed by movements, the chances of procuring a good result in a shorter time are considerably increased.

Sciatica.—Electrical treatment of sciatica is not likely to be of benefit if, from unsuccessful or neglected treatment in the early stages, scar tissue has formed in the sheath and perineural connective tissue and has compressed the nerve fibres. It is most likely to be beneficial when the nerve trunk is in an earlier stage and permanent organic changes have not taken place. After the early acute stage has passed the electrical treatment should be conducted in the way described under *Neuritis*.

When ionisation (with quinine ions or salicylic ions) is applied the pads must be large. One, four inches wide, should be placed on the back of the thigh and extend from the back of the knee to the sacrum. The other, of a similar size, should be placed on the front of the thigh and abdomen. The ions will not penetrate far when vascular tissue is reached, below the skin. Equally good results seem to be obtained when sodium or chlorine ions are used.

The galvanic current can be applied to the patient when in bed.

When diathermy is tried, a small electrode may be placed over the nerve in regions that are tender on pressure. The indifferent electrode is placed on the opposite side of the limb. The current should be very gradually increased and passed for ten or fifteen minutes. Care must be taken not to burn the skin. Other tender regions are heated in the same way, each for the same time. After the diathermy, the high-frequency effluve should be applied in cases in which repeated applications of diathermy fail to relieve the pain. It may also be applied after ionisation.

A third method of electrical treatment is the application of the rhythmic sinusoidal current in full-length baths. This treatment should be reserved for less acute cases. If the application is painful, the other methods should be applied first and the sinusoidal currene used later on, when the acuity of the pain has been reduced.

In cases where cicatricial tissue has developed, the static wave current or static sparks may be successful if the adhesions are around the nerve and the trunk not compressed. Surgical operation may be necessary.

Sexual Disorders.—Electricity has been much used in sexual disorders, but it has not proved of great value.

Most sexual disability is due either to nervousness or over-indulgence, and it is not easy to see how electricity, locally applied could, under such circumstances, have any great value. Erb, however, has advised the use of the constant current, from 5 to 10 milliamperes. A small button-shaped electrode, connected to the positive pole, is applied to the perinæum, and the other larger electrode to be moved up and down slowly over the lower dorsal and lumbar spine. Faradisation of the scrotum with a fine wire metal brush is sometimes of value in cases of impotence.

Sinuses.—Sinuses that refuse to close should be treated by the ionic method, using zinc, or salicylic ions, or the ions in a solution of iodine in potassium iodide. The method of application is described in Chapter V., page 104.

Sprains (see *Arthritis—Injuries of Joints*).

Spring Catarrh (*Vernal Conjunctivitis*).—This very intractable infection of the conjunctiva is sometimes sent for electrical treatment. Ionisation with quinine ions has been recommended.

Stellate Veins (see page 118).

Stiff Joints (see *Arthritis—Injuries of Joints*).

Stricture (*Urethra,* page 121; *Œsophagus,* page 121).

Sycosis.—This may be treated by ionising the suppurating follicles with copper or zinc, needles of these metals being introduced into the infected parts. The whole of the affected skin should afterwards receive zinc ionisation from a pad covering the part.

Synovitis.—(See *Arthritis*).

Tabes (see *Locomotor Ataxy*).

Tinea Tonsurans.—The fungus in the hair roots can be destroyed by ionising the scalp with copper or zinc ions. It is impossible to remove every trace of grease from the scalp and hair follicles, and unless this be done, some hairs will remain infected and afterwards reinfect the scalp. When there is only one small affected patch the ionic method of treatment may be tried. After a thorough wash of the scalp with soap and water, followed by alcohol and ether, a pad soaked in 2% zinc sulphate or copper sulphate is placed in contact and allowed to stop there for half-an-hour. The pad is then connected to the positive pole, and the current passed for ten to twenty minutes. Children will only tolerate small currents.

Tinnitus Aurium sometimes responds to electrical treatment very satisfactorily. A bifurcated electrode is used and make the anode. The electrode is like the metal part of a binaural stethoscope. To its free ends are attached the pads. The latter are placed behind the ears. The current must be increased very gradually or the noises may return worse than before.

The brush discharge from the static machine and the high-frequency effluve, applied locally, have been recommended.

Trachoma.—W. J. Morton originally reported a method of treatment of trachoma by copper ions. A copper rod was slowly passed over the everted lid and a current of 2 to 3 milliamperes or more was passed for two or three minutes. Four to twelve treatments were necessary. Several cures were reported.

Ulcers.—(1) *Chronic Non-Specific Ulcers* improve at once under ionic treatment and heal rapidly. The zinc ion is generally chosen. Occasionally the zinc fails. It is then advisable to apply a solution of iodine in potassium (1% of each) and introduce into the ulcer the negatively charged ions from this solution. The salicylic ion is sometimes effective when the zinc ion fails. The ionic method of treatment of these ulcers will often succeed when all other methods have failed. When the zinc ions are used the base and edges of the ulcer take on a pearly white hue. No further treatment should be given as long as this appearance is maintained; and so long as the edges of the ulcer are growing towards each other it is not necessary to repeat the treatment. If the iodine ions or salicylic ions are used they need not be applied again till three days have elapsed, and then only if the ulcer refuses to fill up.

Ulcers that result from gunshot wounds are frequently slow in healing, and the process of repair often comes to an end. Such ulcers can be made to heal rapidly by means of the galvanic current, provided that they are uncomplicated by sequestra or foreign bodies. The ulcer should be packed with cotton wool soaked in salt solution and covered by a pad in the manner described on page 104. The indifferent electrode should be placed on the opposite side of the limb. The active electrode is made the kathode. Chlorine ions enter the surface of the wound. These have no germicidal action, but the movement of the ions probably stimulates the process of repair of the tissues. If the active electrode is the anode, healing also occurs, but less rapidly. The author has obtained a large number of successful results in military cases by this method.

In some cases, treatment by ionisation fails. The cause of failure may be the pressure of fibrous tissue in the base of the ulcer.

(2) *Corneal Ulcer* (see page 296).

(3) *Rodent Ulcer* (see page 323).

(4) *Syphilitic Ulcers* should be treated by ionisation with the ions present in a 1% solution of iodine in 1% solution of potassium iodide.

(5) *Perforating Ulcers* should be treated in the same manner as syphilitic ulcers.

Urinary Incontinence (see *Incontinence of Urine*).

Vaginitis.—Septic inflammation of the vaginal walls may be successfully treated by ionisation with copper or zinc. A method is described on page 107.

Varicocele.—The pains associated with varicocele is relieved by the application of high frequency to the scrotum. Diathermy would probably be more efficacious. The patient lies on the condenser couch (Schittenhelm couch when diathermy is applied). The scrotum is enveloped in strips of lint soaked in 10% salt solution, and an electrode, made of thin lead plate, is bent so as to fit the lint surrounding the scrotum.

Varicose Veins.—These may receive high-frequency or diathermic treatment on the condenser couch. The veins should be covered with lint strips soaked in 10% saline, and lead plates should be laid over these and connected to the diathermy or high-frequency machine.

Vernal Conjunctivitis (see *Spring Catarrh*).

Vulvitis may be treated by ionisation with copper or zinc. A pad composed of layers of lint is cut to a suitable shape, soaked in a solution containing the desired ion and applied to the part. If there is vaginitis also, the two complaints may be treated simultaneously by zinc or copper ionisation. Sloan's method is described on page 107.

Writer's Cramp.—The electrical treatment of this is unsatisfactory, even if the occupation is left off. The passage of a constant current from the back of the neck to the forehead may be tried. Another method is to apply the same current, but to direct it from the hand to the back of the neck. The anode is placed on the palm if the cramp is of the extensors; on the dorsum if it is of the flexors. A current of from 2 to 8 milliamperes is to be applied twice daily, for fifteen to twenty-five minutes. Complete rest from writing is absolutely essential.

Other forms of "occupation spasm" are to be treated in the same way, the anode placed opposite the affected muscles.

Warts.—Warts can almost always be removed by zinc ionisation. Each wart is transfixed at its base, at the level of the surrounding skin, with a zinc needle. A current of 1 milliampere should be applied for one minute. If the wart is larger than, say, an eighth of an inch in diameter, it should be transfixed twice, in two directions, at right angles. If still larger, three or four times, parallel to each other. The wart becomes paler during the treatment. It afterwards darkens, and drops after about a week. A current of 1 milliampere for one minute is sufficient for each application.

If the wart is flat and very little raised it is difficult to transfix it with a needle. An effective method of treatment of such warts is diathermic sparking (described on page 260). The minute soft warts which appear on the face and backs of the hands can sometimes be made to disappear after ionisation with magnesium. Five per cent. solution of the sulphate is used. If this method is to prove successful, one or two applications only are necessary.

CHAPTER XV

PHYSICAL PRINCIPLES

Nature of Electricity.—Very little is known of the actual nature of electricity. The question is, however, of minor importance in the application of electricity in medicine and the arts, since we are here concerned entirely with the *effects* to which it gives rise, not with the nature of the agent that is responsible for their production. It is necessary, however, that certain fundamental principles should be borne in mind regarding our conceptions of electricity.

In the first place it must be remembered that electricity exists everywhere, permeating all matter, but in a condition of such even distribution and perfect balance that we are unaware of its existence. When the distribution is altered the effects which are termed "electrical" are then made manfest in the effort to regain the balance. In the second place, it must be remembered there is no creation of electricity, although it is convenient to make use of such an expression. We merely alter its distribution, producing in one part an excess, in another part a deficit; hence the origin of the expressions "positive charge" or "positive electricity," and "negative charge" or "negative electricity." It must also be remembered that the subdivision of electricity into various forms, such as static electricity, current electricity, etc., does not imply the existence of so many varieties of electricity, but refers to the different ways in which it can manifest itself.

Of the views that were held concerning the nature of electricity itself, one was that it consisted of an "imponderable fluid" pervading all matter, but that, so long as the distribution was even, neither an excess nor a deficit, there was no outward and visible evidence of it. If the balance was upset, then the effects termed electrical came into evidence. The expressions "positive electricity" or "positive charge" indicated the idea that the fluid was present in excess; "negative electricity" or "negative charge" that it was present in amount less than that in the state of even distribution. This is the "one-fluid theory" of the nature of electricity.

The modern view is that electricity is a material substance consisting of units or atoms that are 1/1800th of the size of an atom of hydrogen. Each atom of matter is supposed to contain one or more of these units or "electrons," as they have been called. A body which contains the normal number of electrons presents no electrical properties. It is only when there is an excess or deficit of electrons that these properties become manifest. When glass is rubbed with silk it is supposed, according to the old theory, to have acquired *excess* of the electric fluid, or, in other words, a *positive* charge. Now when a body *loses* some of its electrons it shows the same electrical properties as a *positively* charged body, and vice versa. It is therefore unfortunate that the term "positive" was arbitrarily chosen to express the electrical condition of a body which, according to modern research, contains a deficit of electrons.

In order to avoid confusion the terms positive and negative are used in their original meaning; the charge on glass after the latter has been rubbed with silk is regarded as a *positive* charge.

(*A*) STATIC ELECTRICITY

Static electricity is most readily produced by friction. If glass is rubbed with silk both acquire an electrical charge. Speaking more correctly, the friction brings about a redistribution of electricity, one of the rubbed bodies acquires an excess of electricity, the other losing it to a corresponding amount. It is commonly supposed that the glass acquires the excess, the silk thereby losing it to an equal degree. The glass is therefore said to be *positively* charged, the silk to be *negatively* charged. Bodies that are electrically charged acquire new properties, the most characteristic of which is their power of attracting or repelling other light bodies. It can easily be shown that they attract other objects that are light and free to move. It can also be shown that a positively charged body will attract a negatively charged body, but that two positively charged bodies, or two negatively charged bodies, will repel each other. Bodies that are similarly charged, therefore, repel each other, and those that are differently charged attract each other. These properties of electrified bodies are demonstrated by the *electroscope*. This instrument is used for the purpose of finding out whether an object is electrically charged or not, and whether the charge is negative or positive (see page 338).

Many other bodies besides glass and silk become electrically charged by friction. The same two bodies always take the same charges when rubbed together. The charge which a body takes depends upon the substance against which it is rubbed, and the charges on the two are always equal and opposite. It is possible to construct a list of substances so that when any pair of them is rubbed together the body higher in the list is positively edectrified and the other is negatively electrified to an equal extent. The following is a list of this kind: catskin, glass, flannel, paper, silk, shellac.

If we rub glass with catskin the glass becomes negatively electrified, while if the same piece of glass is rubbed with silk it is positively electrified.

The electrical charges that are produced by friction remain for a time on the bodies which are rubbed together, and do not at once flow off. The term "static" is applied to such electrical changes to signify that the electricity stays where it is produced. The term conveys the idea of electricity "at rest." Speaking more precisely, the distribution of electricity rendered uneven, in excess on one body, in deficit on the other, remains uneven; the balance has been upset and it remains upset.

Many substances (they were formerly called non-electrics) do not become electrically charged when rubbed together. This is so because they allow the ready passage of electricity along them and from one to another, so that the balance is restored as fast as it is upset, if indeed it can be said to be upset at all. These substances are *conductors* of electricity. Other substances do not allow the ready passage of electricity along them, so that the balance, upset by friction, is not readily restored. The latter substances, formerly grouped together as "electrics," do not conduct electricity, and are now known as "non-conductors" or "insulators."

Conductors and Insulators.—There is no sharp line of demarcation between conductors and non-conductors. All substances are conductors of electricity, more or less, but some of them conduct it so exceedingly badly that they are, practically, insulators. A perfect insulator would be an absolute vacuum, but as an absolute vacuum exists only in theory—being, in practice, unobtainable—we are at present without a perfect insulator.

The metals are good conductors. So also is carbon. Aqueous solutions of acids, alkalies and salts are less good conductors. The tissues of the body that contain salts in solution conduct electricity fairly well. Vulcanite, ebonite, shellac, sealing-wax, glass, silk are insulators. Distilled water is an insulator. The skin, when moist, is an indifferent conductor. When dry it is a very bad conductor. The conduction of electricity by fluids and by the tissues of the body forms a subject of extreme importance for the correct understanding of the action of electricity on the body, and was considered in Chapter I.

The conducting power of some substances varies with their physical state. For instance, metals when heated do not conduct as well as they do when they are cold. Carbon, on the other hand, conducts better as its temperature is raised. Absolutely pure water is a very good insulator, but the addition of a slight trace of a salt brings down the resistance enormously. The human skin when dry has a very high resistance, but when well wetted becomes a very fair conductor; again dry air is one of the best insulators known—moist air is a poor conductor. Further, the insulating power of air is increased as its pressure is increased, while, on the other hand, as the pressure is decreased, its insulating properties are decreased until a degree of diminution of pressure is reached when it becomes a moderately good conductor. Further reduction of the pressure now increases its resistance, and when the pressure falls to zero electricity cannot be conducted at all, a perfect vacuum being a perfect insulator. The conduction of electricity by the so-called vacuum electrodes used in medicine illustrates the fairly good conduction of electricity along air at a certain degree of diminution of pressure.

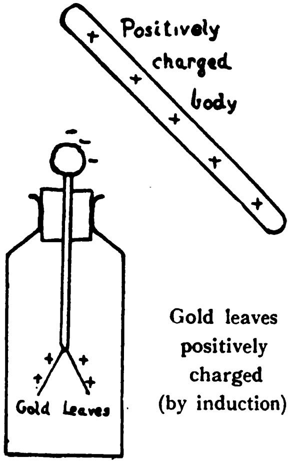
In the application of electricity for medical purposes we have to deal mainly with the conduction of electricity through fluid conductors. The subject thus becomes extremely important, and, when it is clearly understood, a ready explanation is obtained of one of the modes of action of electricity in producing physiological and therapeutic effects on the body. The matter was considered in detail in Chapter I.

When a conductor is mounted on some insulating material and not in contact with any other conductor, it is sand to be "insulated," because electricity when produced on it cannot escape.

Induction.—When an electrically charged body is brought near a conductor, without touching it, the latter becomes electrically charged itself. The first body is said to *induce* electricity on the second. The first body does not part with any of its charge. It induces a redistribution of electricity on the second body, one part of the latter acquiring more than normal (a positive charge), another part therefore containing less than its normal amount (a negative charge). These two induced charges take up definite positions. Suppose that the original body was positively charged : since like charges repel each other and unlike charges attract each other, the negative *induced* charge takes up a position on the second body as near as possible to the first. The positive *induced* charge is repelled as far away as possible from the first. If the first body is now removed, the two induced charges neutralise each other—*i.e.* the distribution again becomes uniform and the second body now shows no sign of an electrical charge. Supposing that the second body is insulated : if the first body is again approached the charges are again induced. If the second body is now momentarily connected to earth, say by touching it, the positive induced charge is now repelled to earth. If the first body is now removed, the second body is now left with a negative charge upon it, because the repelled positive charge cannot return, since the second is insulated.

The phenomena of induction and of attraction and repulsion can be well shown by the electroscope.

The Electroscope.—In its simplest form this instrument consists of two gold leaves suspended from the tip of a vertical metal rod. They lie in contact, face to face. In order to protect them they are enclosed in a glass jar, the mouth of which is closed by a cork, through which the metal rod passes, so that the leaves hang freely within the jar. The other end of the rod is outside the jar, and it bears a metal ball (Fig. 68).



Gold leaves positively charged (by induction)

FIG. 68.—Electroscope.

When a charged body is brought near the metal ball a charge of opposite nature is induced on the latter and an equal charge, of the same nature as that on the charged body, is repelled to the gold leaves (Fig. 68). The latter, being similarly charged, repel each other and diverge. When the charged body is removed the induced charges neutralise each other and the leaves fall together again. But if the metal ball is momentarily touched before the charged body is removed, the induced charge that is present on the gold leaves is now repelled to earth and the leaves, being now no longer charged, fall together. If now the original charged body is removed, the charge that was induced on the ball now spreads itself over the metal rod and the leaves. The latter diverge once more.

Suppose that the original body was positively charged, the leaves would now be negatively charged. . If, now, a second charged body, the nature of the charge being unknown, be brought near the ball without touching, it will induce on to the leaves an extra charge of the same nature as that on itself. If the leaves diverge still further, the extra charge on the leaves is of the same nature as that pre-existing on them—viz. negative. The unknown charge is therefore negative. But if the leaves approach one another the unknown charge is positive.

Density: Potential.—An electrical charge resides *only on the surface* of a conductor. The density of a charge is the amount of electricity per unit of surface area. If the electricity is not evenly distributed over the surface, the density must vary in different parts. It is only over the surface of a *sphere* that the distribution is even, so that on a sphere the density is the same all over. If the surface of a conductor is not even, the distribution of the electricity will be uneven; it will be more concentrated on the parts that are more convex, while the greatest concentration will be on edges and points. The density will therefore be greatest at edges and points, and here the electricity tends to leak off from the conductor.

The term "potential" is frequently used in reference to electrical charges. Conductors are said to be charged to a high potential or to a low potential. The potential of a charge does not refer to the actual quantity of electricity, but to the quantity in relation to the surface area of the conductor on which it resides. The following comparison may make the meaning of potential clearer. A certain quantity of air pumped into an inexpansible vessel would exert a certain pressure on the walls; if the capacity of the vessel was reduced to one-half, the same quantity of air (measured in the uncompressed state) would exert double the pressure, although the quantity of air would be the same. In the case of the electrical charge, a certain quantity of electricity would charge a conductor to a certain potential. The same quantity of electricity would charge a conductor of half the capacity to double the potential. In the latter case the density of the charge—*i.e.* the *quantity* of electricity per unit of area—is doubled and the result is that the electricity is at a higher potential or "pressure"; the electricity has a greater capacity for doing electrical work and overcoming resistance. Electricity at high potential flows or tends to flow to parts where it exists at lower potential, and if the difference of potential is high it may overcome the resistance of the air—that is, if air separates the two conductors charged to different potentials—and pass across in the form of long sparks.

The potential of the earth's surface is taken as zero. All bodies that are connected to earth by conductors (or "earthed") must be at the same zero potential.

Positively charged bodies may be regarded as bodies charged to a potential above zero; negatively charged bodies as those charged to a potential below zero.

Capacity.—The quantity of electricity that a conductor is capable of receiving is determined by the "capacity" of the conductor. As the electricity resides only on the surface, the capacity of a conductor depends upon its surface area. For electrical purposes the capacity is measured, not by the surface area, but by the quantity of electricity required to raise its potential from zero to unity. If a unit quantity of electricity is required to raise the potential from zero to unity, the conductor is said to have a unit capacity. The unit of capacity is a "farad."

When we say that a conductor has a certain capacity, it is not to be thought that it is capable of holding only a certain fixed charge. The amount of electricity that a conductor will hold depends, apart from its surface area, on the potential of the source of supply; if this is sufficiently high, electricity will pass to the conductor, raising its potential till the electricity begins to leak off. If, on the other hand, the potential of the source of supply is low, electricity will pass to the conductor till the potential of the charge on the latter equals that of the source of supply, and no more electricity can then pass. To return to the air pressure analogy. A pump capable of delivering air at any pressure will continue to force air into a vessel, raising the pressure within it higher and higher till the air escapes through a valve; on the other hand, if the pump delivers air at a low pressure, the pressure inside the vessel will soon equal that of the air supplied by the pump, and then no more will pass in.

The capacity of a conductor may be greatly increased by bringing close to it a second conductor without actually touching it, the two being separated by some insulating material, such as the air, or glass, ebonite, etc. Such an arrangement of conductors is termed a *condenser,* because the first conductor is now able to hold a much larger quantity of electricity than it could before the second conductor was in close apposition.

Condensers.—A condenser consists of two conducting surfaces separated by some insulating material. The latter is sometimes called the "dielectric." The capacity of a condenser depends on: (*a*) the area of the conducting surfaces—the greater the surface the greater the capacity; (*b*) the thinness of the dielectric—the thinner the dielectric the greater the capacity; (c) the material of the dielectric—glass gives a condenser a greater capacity than the same thickness of air.

The simplest form of condenser consists of two metal sheets of equal size, facing each other, with a layer of insulating material of larger area interposed, allowing them to come into close apposition without actual contact with each other.

The most familiar form of condenser is the well-known as Leyden jar (Fig. 69), which in its most common form consists of a glass bottle which is partially coated inside and out with tin-foil, and provided with a stopper of some insulating material through which passes a stout wire. On the outer end of this is mounted a metallic knob, and from the inner end hangs a length of brass chain sufficient to make good contact with the inner coating. Here the two tin-foil surfaces are the conductors —sometimes called the "armatures" —and the glass the dielectric.

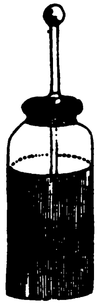


FIG. 69.
Leyden Jar.

To charge a condenser one of the conducting surfaces is connected to a source of electricity, and the other surface is connected to earth. In the case of the Leyden jar, the metallic knob is connected to the source of the electricity, while the outer coat is brought into contact with earth by standing the jar on a table, or by holding the jar in the hand, grasping the outer coating. The inner coating is charged—by conduction—from the source of supply, while the outer coating is charged by *induction*, the induced charge of the *same* sign being repelled to earth, that of the *opposite* sign remaining on the outer coat, attracted by the charge on the inner coat.

Suppose that the potential of the source of supply is + 1. The inner coat of the jar when connected to this source is thereby charged to the same potential. But a larger quantity of electricity is required to charge it to this potential than would be required if the inner coating stood by itself. Suppose the potential of the induced charge on the outer coat is —$\frac{1}{2}$. The potential of the inner coat is now 1—$\frac{1}{2}$ or +$\frac{1}{2}$. The inner coat is thus brought to a lower potential than that of the supply, and, therefore, more electricity must pass to the inner coat until the potentials are equal.

To discharge the jar, a bent wire is placed with one end against the outer coating, and while retaining it there, the other end is brought gradually closer to the knob. Presently a spark passes and the jar is said to be discharged.

As a matter of fact it is not completely discharged unless the wire has been brought in contact with the knob and the outer coating at the same instant, for if we try again to discharge the jar another spark will pass, though much smaller and shorter than the first. This is due to the "residual" charge, as it is called. It may be as well to mention here that when we discharge a jar the spark is not single—passing once only from wire to knob, or vice versa; what appears to be a single spark is really a series of sparks passing alternately in opposite directions at an enormously rapid rate. The oscillation may, under suitable circumstances, reach a frequency of thousands or even millions per second. The discharge of a condenser is therefore a current of high-frequency oscillation or alternation, providing certain requirements in the circuit along which the discharge takes place are fulfilled. These have been mentioned in the chapter on high-frequency.

The oscillatory discharges of condensers are used for electro-medical treatment, and their application form an important branch of modern electrotherapy—viz. high-frequency and diathermy. Condenser discharges have been recently introduced for the purpose of muscle-testing and treatment of paralysis and other conditions.

The Production of Static Electricity for Medical Purposes.—Static electric machines are used to generate a continuous supply of static electricity, and are of two kinds, frictional and inductive. The old-fashioned revolving glass cylinder, with an amalgamated leather rubber and brass collector or prime conductor, is an example of the frictional type. This type of machine is never used for medical purposes, and is now seen only in physical laboratories.

Induction or influence static machines are much more reliable. The precise way in which they work is not known with certainty.

The principle may be outlined as follows :—

A body, *A*, is charged positively and brought near another body, B. B is therefore charged by induction, as described under "Induction." *B* is momentarily connected to earth, whereupon the positive induced charge escapes, and the negative induced charge remains. *B* and *A* are now separated from one another. The induced negative charge on *B* is collected and stored on another fixed and insulated conductor, while the original positive charge on *A* can be used over and over again to induce fresh charges. The mechanical energy expended in separating the oppositely charged bodies, *A* and *B*, is converted into electrical energy.

A simple device, known as the "electrophorus," serves to illustrate the production of electricity by induction. It consists of a disc of insulating material, such as ebonite, and a disc of metal, slightly smaller in diameter, attached to a handle of insulating material. The ebonite disc is rubbed with catskin or silk, so as to give it a charge. The metol disc, grasped by its handle, is placed on it. Charges are induced on the metal. The latter is then touched, whereupon the induced charge, of the same sign as that on the ebonite disc is repelled to earth. The metal disc is now removed and the induced charge —of the opposite sign to that on the ebonite disc— remains on the metal. It can be transferred to an insulated conductor. The metal disc is now again placed on the ebonite disc, and further charges can be induced on it, one being repelled to earth, and the other transferred to the insulated conductor. The ebonite disc would not part with any of its charge if it were perfectly insulated. In practice, however, it slowly leaks off to the atmosphere which slowly conducts it away.

Two types of influence machine have been described in Chapter XIII.

(*B*) CURRENT ELECTRICITY

If two conductors at different potentials are connected by a wire, the difference of potential will be equalised and a current of electricity, of momentary duration, will pass along the wire. If the conductor at the higher potential can be continuously supplied with electricity, a continuous current will flow along the wire. Continuous currents of electricity can be obtained by *chemical, thermal* or *mechanical* methods. The currents that are supplied by the different types of cell are obtained by chemical methods. Batteries of these cells form an important source of electrical supply for medical purposes, and the principles on which they work will be considered first.

Production of Electrical Currents by Chemical Methods.—If two dissimilar metals are brought into contact, a slight difference of potential is set up between them, that of one being raised (positive), that of the other being lowered (negative). The degree of difference is always very slight, and it varies according to the metals taken, and it does not depend upon the amount of metal or the extent of surface in contact.

Here again it is possible to draw up a list of substances—metals or conductors in this case—each of which will be positively electrified when brought into contact with any metal succeeding it, and negatively electrified with any metal coming before it in the list:

+ Sodium
Zinc
Lead
Tin
Copper
Silver
Platinum
—Carbon

Carbon is not a metal, but is included in this list on account of its good conducting properties, and from the fact that it is now used so much in all branches of electrical work. If zinc and copper be brought together, zinc is positive and copper is negative, while if copper and carbon be brought together, the copper is positive and the carbon negative. The more one metal is removed from another in the list, the greater is the difference of potential. It will be noticed that those metals nearest the + end of the list are the most oxidisable, while the reverse holds goods for metals at the — end.

It is impossible, however, to obtain an electrical current by simply bringing dissimilar metals into contact. If the circuit is completed by connecting together the free ends of the two metals in contact, either directly or by means of a third metal, new contacts of dissimilar metals are made and the difference of potential first set up would be effaced. Apart from this, the production of a continuous current of electricity, by simply bringing dissimilar metals into contact, would be impossible, according to the principle of the conservation of energy, seeing that the metals are not altered or used up. If, however, the two metals in contact are immersed in some fluid that is capable of acting chemically on one of them or acting more vigorously on one than on the other, a continuous current can be produced while the chemical action proceeds. Thus if a piece of copper and a piece of zinc are fixed together, end to end, the copper becomes negatively charged, the zinc positively charged. If the joined metals are immersed in dilute sulphuric acid, a circuit is now completed and an electrical current flows from the zinc, through the acid, to the copper, and through the copper into the zinc. Simultaneously, the zinc is slowly dissolved by the acid. If the joined metals are bent so that only the free ends are immersed in the acid, the junction being outside, an electrical current will flow as before and in the same direction. Such an arrangement is known as a " simple voltaic cell." It serves to illustrate the chemical changes that occur during the production of an electrical current and to explain the meaning of some commonly used terms.

Voltaic Cell.—A simple voltaic cell may be constructed by filling a beaker with 10% sulphuric acid, partially immersing it in two strips of metal, one of zinc, the other of copper. These strips are placed parallel to each other and with one end of each above the surface of the acid. If the strips do not touch one another, above or below the surface of the acid, the following changes occur. The zinc gradually dissolves in the acid, and zinc sulphate and hydrogen are formed. The former dissolves, while the latter escapes in the form of bubbles. These are seen to form and to escape at the surface of the zinc. If, however, the zinc is pure it is not dissolved by the acid and it undergoes no chemical change till it makes contact with the copper. If the contact is made *outside* the acid, either directly or by means of a wire, the zinc begins to dissolve and the same chemical change takes place. The hydrogen bubbles, however, make their appearance *on the copper,* not on the zinc. Some escape from the copper to the surface of the acid, but most of them adhere to the metal and soon cover it completely. While the zinc is dissolving a current of electricity passes continuously around the circuit composed of the metal strips, their connecting wire and the dilute acid. The current starts in the cell where the zinc is in contact with the acid. It passes through the acid to the copper plate. It then passes up the copper plate, outside the acid, along the connecting wire, and then across to the zinc plate. By passing down the zinc to the acid again, the passage along the circuit is completed. The direction of the current of electricity is indicated by the arrows in Fig. 70.

If impure zinc is used chemical changes similar to those described would have occurred, and the current would have passed in the same direction. In addition, however, small "parasitic" currents would also have been produced. Commercial zinc contains small quantities of other metals. There are, therefore, dissimilar metals in contact, and when they are immersed in sulphuric acid, currents are formed in the way mentioned in the preceding paragraph.

Certain names are given to the various parts of a voltaic cell, and as they are continually used it is necessary to be quite clear regarding their meaning.

In any cell there is an *external circuit* and an *internal circuit,* a *positive plate and pole,* and a *negative plate and pole.* It is important to distinguish between *plate* and *pole.*

In Fig. 70 that part of the circuit within the fluid of the cell is called the *internal circuit*, while that outside is the *external circuit*. In any circuit or part of a circuit, that part from which the current is coming is positive to a part to which current is flowing.

Bearing this in mind, it will be seen that that portion of the zinc which is below the level of the fluid is positive to that part of the copper which is also below the level of the fluid. In the external circuit we see that the part of the copper outside the liquid is positive to the corresponding part of the zinc. These *dry* portions of the plates are called the *poles*. If we attach a wire to each of these, the free extremities of these wires become the *poles*.

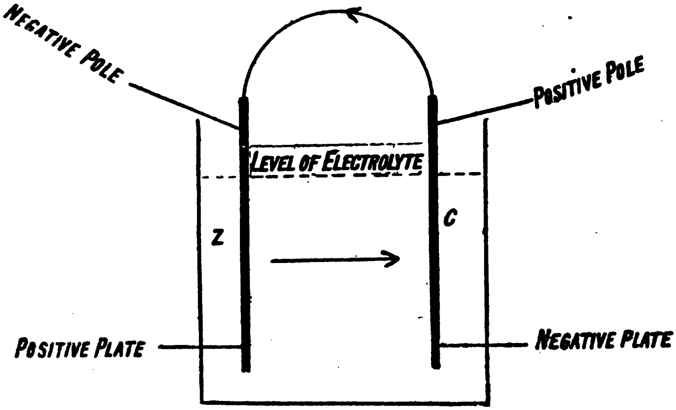


FIG. 70.—Plates and Poles of a Voltaic Cell.

Thus it will be seen that the wet portion of the zinc is the *positive plate* and the dry portion is the *negative pole*, while the wet portion of the copper is the negative plate, the dry portion is the positive pole. This may seem very confusing, but it is not really so, and if the student will take the trouble to get the idea thoroughly there is little chance of his being confused by any of the various arrangements of circuits he will meet with in future.

It is customary when referring to the plates of a battery to speak of the *poles* and not of the *plates*. The zinc is thus the *negative pole* and the other element, be it carbon, copper, or platinum, is the *positive pole*.

The electrical current that flows around the circuits of a voltaic cell soon diminishes in strength. It becomes feebler and feebler and finally ceases altogether.

The explanation of this is that by the accumulation of minute bubbles on the copper plate the latter is practically transformed into a hydrogen plate. The latter is electro-positive to zinc, and tends to set up a current in the reverse direction. Also, the film of gas forms a layer of high resistance to the flow of the original current.

A cell in this condition is said to be "polarised." The prevention of polarisation is one of the most important objects in the design of a useful cell. The great variety of cells that have been devised have their origin in the various methods that have been adopted to prevent polarisation, and thus give as nearly as possible a constant current during their period of activity.

A simple cell like that described is useful for the purpose of demonstration, but is of no value for medical purposes, because the current so quickly diminishes on account of polarisation, and soon falls to zero. Polarisation can be prevented in various ways. One way is to add an oxidising agent, such as potassium bichromate, to the acid solution. The hydrogen is oxidised as soon as it is formed. This method is used in the *Poggendorff cell*. In this cell, known also as the " bichromate " cell, carbon is used instead of copper. In the *Leclanché* cell zinc and carbon are used. The zinc is immersed in a solution of salammoniac (ammonium chloride) contained in a glass jar. The carbon plate is placed inside a porous pot and, packed tight round it, are fragments of manganese dioxide and powdered carbon. The porous pot, thus filled, is placed in the jar containing the salammoniac solution. When the zinc and the carbon are connected by a wire, a current passes from the carbon to the zinc *outside* the cell, and from the zinc to the carbon inside the cell. Fluid is unable to pass through the wall of the porous pot, but the electric current readily traverses it. The zinc dissolves in the salammoniac solution, forming a double chloride of zinc and ammonium, while ammonia gas and hydrogen are liberated. The ammonia dissolves and the hydrogen is oxidised by the manganese dioxide; if, however, the cell is made to give a current continuously for several minutes, polarisation begins and the current begins to diminish in strength. If the cell is allowed to rest, the free hydrogen will be oxidised, and the cell will then provide a current of undiminished strength.

Dry Cells.—These have almost entirely supplanted other cells for medical purposes. They are small and clean, and a number can be packed away in a case of small dimensions, so that a portable battery is at hand. They are really modified Leclanché cells, in which the solution of salammoniac is replaced by a moist, pasty composition. They tend to run down very slowly even if they are not used, but they will last from six months to two years if their use is not excessive and the best types are used. The battery of dry cells in the portable cases can be replaced when exhausted, and some makers allow 50% of the original price for the old cells in exchange for new ones.

These dry cells can be obtained from most electrical dealers.

Leclanché cells have an E.M.F. of about 1·5 volts when new, and their internal resistance is from ·75 to 1·5 ohms—the smaller the cell the higher the internal resistance. They are now almost universally used in portable batteries.

Accumulators.—Accumulators, or storage batteries, as they are often called, are the most satisfactory means we possess of obtaining electricity from chemical action. The name "storage battery" is not correct. We do not store electricity in an accumulator, but if we take one that is exhausted and drive a current through it in the opposite direction to the current it gave out when working, we can restore the plates to their original condition and give it a new lease of life, so to speak—and so long as we do not charge or discharge the cell at a greater rate that that for which it is designed, this process can be repeated almost indefinitely.

An accumulator consists of a vessel containing sulphuric acid diluted till its specific gravity is 1200. In the acid are immersed lead plates made in the form of grids. Two of these plates are negative, one positive. The spaces of the grids are filled with a paste composed of litharge in the case of the negative plates, and red lead in the case of the positive. The plates lies close together, face to face, without touching. The internal resistance of an accumulator cell is extremely low. Each cell gives 2 volts under ordinary working conditions, and continues to do so until about 75% of its charge is spent. If the cell be discharged still further the voltage begins to fall. It should never be allowed to fall below 1·8, nor should it ever be left at this latter figure for any length of time; it should be recharged at once. If this be neglected, a white deposit appears on the plates—insoluble sulphate of lead. This increases the internal resistance and diminishes the capacity of the cell, and it may be safely stated that a cell which has once become markedly sulphated can never be restored to its original condition. All cells have a certain rate of charge and discharge, which depends on the size and capacity, and which is usually about 10% of the full capacity. That is, a sixty-ampere-hour cell should not be charged with a greater current than 6 amperes. This, continued for ten hours, would fully charge the cell.

The charging of an accumulator should be continued until the voltage rises to 2·5 volts per cell. The voltage remains at this for a short time only, after charging is stopped, when it declines gradually to 2 volts.

Accumulators are also known as "secondary batteries" in contradistinction from the "primary batteries" as those previously described are often called. Primary batteries cannot be recharged like secondary batteries when exhausted. A fresh supply of chemicals must be added.

Bichromate Batteries.—For the thermo-cautery and working large spark coils the bichromate battery is the most easily managed where some form of *primary* cell must be used. The plates are of zinc and carbon. They should be of large size, placed close togther to reduce the internal resistance to its lowest limit, and arranged so that they may be readily removed from the exciting fluid the moment the current is no longer required. The zincs must be kept well amalgamated. The exciting fluid is prepared as follows:—1 pound of potassium bichromate is dissolved in 8 pounds of hot water. Then add slowly 2½ pounds of strong sulphuric acid, stirring constantly all the time. While still hot, dissolve in the mixture 3 ounces of bisulphate of mercury. Each cell, when freshly charged, has an

E.M.F. of 2 volts, but this tends to decline as the cell is used—due to gradual weakening of the exciting fluid. When this becomes green in colour it should be thrown out and fresh solution put in. These cells should be thoroughly washed and cleaned every three or six months, according to size, and care taken to remove all the crystals of chrome alum which will be found sticking to the plates and acid vessel. The zinc plates are gradually dissolved and will eventually have to be replaced. This is not difficult in most forms now obtainable.

The current produced in the ways described—*i.e.* by chemical means—is known sometimes as the "galvanic" current, sometimes as the "constant" current, by reason of its unvarying direction and uniformity of strength. The "direct" current is also a constant current, but the name "direct" is usually applied to it when it is obtained from the main.

Electrical currents can also be obtained by mechanical methods. These will be described later.

The Measurement of Electrical Currents.—This is a subject of great importance in the application of electricity for treatment and diagnosis. During the flow of the current, electricity is constantly passing along the circuit, and the terms "strong" or "weak," as applied to the current, are used in reference to the *quantity* of the electricity that is passing. The strength of an electrical current depends upon two factors: (1) the electro-motive force and (2) the resistance of the circuit. These terms will be explained.

Electro-Motive Force.—Whatever produces or tends to produce a transfer of electricity is called electro-motive force. Thus, when two electrified conductors are connected by a wire, and when electricity is transferred along the wire from one to the other, the tendency to this transfer which existed before the introduction of the wire and which, when the wire is introduced, produces this transfer, is called the electro-motive force from the one body to the other along the path marked out by the wire.

The water analogy will perhaps help to make this clearer. If two vessels containing water be joined by a pipe and if we increase the pressure in one of them, the water will flow from the one in which the pressure is greater until the pressure in both becomes equal. Again, if the water is at a higher level in one vessel than in the other, it will flow from the former to the latter until the level is the same in both. In the same way when any two electrified bodies are joined together by a wire, electricity will flow from the body on which the charge exists at high potential to the body on which the charge exists at lower potential. The inherent force which starts and maintains the current is what is known as electro-motive force—briefly written E.M.F. The potential of the earth is always taken as the zero of electrical potential.

The unit of E.M.F. is the "volt." A single Daniell cell produces an E.M.F. that is very slightly greater than one volt.

Resistance.—It has already been mentioned that different substances vary enormously in their power of conducting electricity, some conducting it readily, others so badly that they are practically non-conductors or insulators. However well a substance conducts electricity there is always some resistance to the flow.

The resistance of a conductor depends on certain conditions.

It varies

(*a*) Directly as the length.

(*b*) Inversely as the area of the cross section.

(*c*) With the nature of the material of which the conductor is made.

(*d*) To a certain extent with the temperature.

(*a*) and (*b*) are sufficiently obvious. With regard to (*c*), a conductor made of silver is found to have a lower resistance when compared with one made of any other material of similar shape and size. The resistance of copper is very slightly greater than that of silver. Platinum has a resistance about six times greater than that of silver and iron about nine times greater.

As a rule, alloys have a resistance much greater than pure metals. An alloy known as German silver has a resistance about fourteen times greater than that of silver, while another, called rheostene, has about forty-four times the resistance of copper. Speaking generally, the resistance of metals increases with an increase in temperature. Carbon and acqueous solutions of salts, acids and bases decrease in resistance as the temperature rises.

In speaking of resistance, it is useful to have a unit so as to be able to compare the resistance of various circuits or the different parts of a single circuit. The unit of resistance is called the "ohm," after the scientist who formulated the law which is known by his name. An ohm is represented by the resistance of a column of pure mercury at 0° C. of a uniform cross section of one square millimetre and 106 centimetres long.

The Unit of Current.—The unit of current is the "ampere." It is the current produced when an electro-motive force of 1 volt acts through a resistance of 1 ohm. The strength of a current depends upon the electro-motive force and resistance. If the electro-motive force is increased, the current will be increased. In other words, increase of the force that produces the transfer of the electric fluid (or electrons) will cause a large quantity of electric fluid (or electrons) to pass along the circuit, while increase of the resistance to the passage of the fluid (or electrons) will lessen the quantity of fluid (or electrons).

The relation between strength of current, electro-motive force and resistance is stated in Ohm's law.

Ohm's Law.—Ohm's law is as follows:—The current varies directly as the electro-motive force and inversely as the resistance.

Expressed in symbols it is:

$$C = \frac{E}{R} \quad \text{where}$$

C = The current.
E = Electro-motive force.
R = Resistance.

From the above equation we obtain

$$E = CR$$

and

$$R = \frac{E}{C}$$

so that with any two of the factors given, the value of the third is obtainable by a simple calculation. This is probably the most important law that has been laid down relating to electricity, and is one that the student should be thoroughly familiar with in all its aspects. It underlies every intelligent application of the electrical current in medicine.

Other Practical Units.—(1) *Unit of Quantity.*—This is the "coulomb" and represents the quantity of electricity corresponding to a current of 1 ampere flowing for one second.

(2) *Unit of Work.*—The unit of the work done is known as a *watt*. It is the product of the volts and the amperes. A current of 1 ampere at a pressure (E.M.F.) of 1 volt flowing for one hour is called *one watt hour*. The Board of Trade unit, as used by all supply companies, is 1000 watt hours. A current of 10 amperes at 100 volts flowing for one hour represents 1000 watt hours, for which the usual charge is sixpence. This is not a unit used in medical electricity, but, as many will obtain their supply from the street mains, it is as well to know what a Board of Trade unit really means.

(3) *Unit of Capacity.*—It was previously mentioned that the capacity of a conductor was measured, not by its surface area, but by the quantity of electricity required to raise its potential from zero to unity. If a coulomb is required to raise the potential of a conductor 1 volt, that conductor is said to have a capacity of 1 *farad*. The size of such a conductor would be so enormous that the *microfarad* —that is, one-millionth of a farad—is taken as the unit of capacity.

Internal Resistance.—This refers to the resistance to the flow of current *inside* a generator or originator of electro-motive force. In the case of dynamo-electric machine it is the resistance of the copper conducting wires with which the machine is wound —and in the case of the battery it is the resistance of the solution between the plates. In the former case it depends on the length and size of the wires; in the latter on the nature of the solution, the area of the plates, and their distance from each other. For a generator to produce a large current it is essential that its internal resistance be kept very low. A resistance inside a cell has to be overcome just the same as if it were in the external circuit, and where the external resistance is very low, a high internal resistance would have a very serious effect on the output of current. On the other hand, with a very high resistance in the external circuit the internal resistance does not signify very much on account of the small proportion it bears to the total resistance of the circuit. To take an example: if the internal resistance of a cell be 3 ohms, and the resistance of the external circuit be 1 ohm, three-fourths of the E.M.F. of the cell will be used up in overcoming its own resistance, leaving only one-fourth of the original E.M.F. available for the outer or useful circuit. If again, the internal resistance be the same, and the external resistance be 97 ohms, then only 3/100 of the E.M.F. will be used up inside the cell, leaving 97/100 available for the outer circuit. In the first example 75% of the total E.M.F. was wasted in the cell, in the second only 3%.

Arrangements of Cells.—If we have a number of cells of any kind we can join them in various ways to suit our requirements. Suppose we have twelve cells, each of which is capable of supplying a current of 1 ampere at an E.M.F. of 1 volt. It will be more convenient for the sake of clearness to assume that the cells have no internal resistance. We will also suppose that we have a 12-volt incandescent lamp with which we wish to examine some part or cavity of the body. This lamp requires an E.M.F. of 12 volts to bring it to full incandescence. To obtain this we join the positive pole of the first cell to the negative of the second, and the positive of the second to the negative of the third, and so on to the end of the row, so that we have a free positive pole at the first cell, and a free negative pole at the twelfth, thus:—

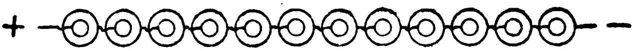


FIG. 71.—Diagram of Twelve Cells joined in Series.

If we now connect a voltmeter to the two wires from the ends, the instrument will register 12 volts, and if we replace the voltmeter by the lamp it will light up to its full candle-power.

The cells as arranged above are said to be connected in *series*, and the effect of the arrangement is to increase the voltage directly as the number of cells—the total E.M.F. being equivalent to the E.M.F. of one cell multiplied by the number of cells. It does not increase the number of amperes beyond what is available from a single cell—that is, 1 ampere, which is probably more than the lamp requires. Now suppose we have a cautery which has a resistance of 1/12 ohm and requires a current of 12 amperes to bring it to the proper heat. It is quite clear that the series arrangement will not do, as the amount of current available is quite insufficient to heat the cautery. Also it will be seen that an E.M.F. of 1 volt is all that is necessary to send a current of 12 amperes through a resistance of 1/12 ohm. Thus we have no object in increasing the voltage beyond that given by one cell, but the amperage of the current must be increased till it reaches 12. We now join all the positive poles together and do the same with the negatives, thus :—

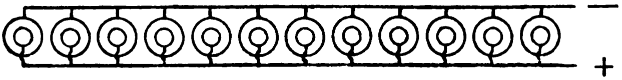


FIG. 72.—Diagram of Twelve Cells joined in Rarallel.

The result here is the same as if we had one big cell twelve times the capacity of a single cell. The voltage of any given cell is the same whatever the size, but the larger the cell the greater the quantity of current it is capable of supplying, because the internal resistance is correspondingly lowered. We will now find that the difference of potential between the terminals of the arrangement is just 1 volt, but a current of 12 amperes can be obtained, so that if we connect up the cautery it will glow a bright red and be ready for use. The cells connected as above are said to be arranged in *parallel*.

Various combinations of the series and parallel arrangements are also possible. If we wanted a current of 2 amperes at a pressure of 6 volts, we would arrange the first six cells in series, and also the second six cells in the same way, and then join these two sets in parallel. This is a series-parallel arrangement—other modifications of which will suggest themselves.

Current Density.—When a current flows along a narrow conductor its *density* or "concentration" will be greater than that of the same current when it flows along a broad conductor. The density of a current in a conductor is the strength of the current divided by the cross-sectional area of the conductor. It is of great importance, when applying currents to the body, to avoid too great a density. The amount of current that the body can tolerate depends upon the degree of stimulation of the sensory nerve-endings in the skin, and the force of contraction of the underlying muscles. The greater the density, the stronger the stimulation and the more violent the contraction. So if the current enters and leaves the body through small electrodes, only weak currents can be passed. If we wish to employ large current we must use large electrodes, and see that they are well adapted to the part. For example, if we wished to apply a current of 50 milliamperes to a limb, and used electrodes, say, one square inch in area, the patient would experience a very sharp pain at the points of contact, and if the application be continued for some minutes, a blister or even an ulcer would eventually form. The reason is that the 50 milliamperes pass through an area of one square inch. If we use larger electrodes, say five inches by five inches, the current density, instead of 50 milliamperes per square inch, would be only 2 milliamperes per square inch. In this way we can employ the same amount of current without discomfort or harm to the patient.

Electric Current and Magnetism.—There is one other peculiar manifestation of electricity when passing through a conductor that has not yet been mentioned. If we take a wire through which a strong current is passing, dip it into some iron filings and then remove it therefrom (the current still flowing), some of the filings will be found attached to the wire and will not all fall off when the wire is shaken, but if we stop the current flowing they all fall away at once, and so long as the current is not flowing the wire will not pick up any more. The reason for this is, that when an electric current flows through a wire there is always a field of magnetic force surrounding it. The lines of magnetic force are at right angles to the direction of flow of current. This magnetic field is a necessary accompaniment of an electric current, and is inseparable from it. It is the presence of this magnetic field which causes the magnetic needle to be deflected in the way to be described later.

The Magnetic Needle.—If a straight piece of hard steel wire, such as a knitting needle, be magnetised, and suspended so as to be free to move in any direction, it will gradually come to rest, with one end pointing to the north and the other to the south. These ends are called the North Pole and South Pole respectively, and one is a necessary accompaniment of the other. That is to say, if we take any piece of magnetic substance, one end of which shows the presence of magnetism of the north variety—then the other end will be also magnetic, but of the south variety. If we take a bar magnet and cut it through at the middle where the magnetic attraction seems weakest or even lost, the result is two complete magnets, each having a north and a south pole.

The knitting needle arranged as above is merely another form of compass, and both are really bar magnets.

Properties of Magnets: Attraction and Repulsion.—Magnets possess properties analogous to those of electrified bodies. Like magnetic poles repel one another; unlike poles attract each other. A magnet is also able to *induce* magnetism in a piece of iron or steel that is brought near to it without actually touching it. Any one pole of a magnet will induce magnetism of an *opposite* kind in that part of the iron that is nearest to it, and of the *same* kind in that part that is farthest away. It is for this reason that magnets attract particles of steel or iron. Magnetism is induced in them—that of the same kind being farther off than that of the opposite kind, so that the particles are attracted with a greater force than that with which they tend to be repelled. It will be remembered that electrified bodies also attract other light bodies, because changes are induced on them.

Lines of Magnetic Force.—Particles of iron or steel and magnetic needles, when brought into the neighbourhood of a magnet, at once arrange themselves in definite lines. Magnetism is induced in them, and they take up positions determined by the resultant of the attracting and repelling forces. The lines along which the magnetic induction acts are known as the "lines of magnetic force." As the pole of a magnet is approached, the force of induction increases and we speak of an increased number of lines of force in the region of the poles. Fig. 73 shows a bar magnet with the surrounding lines of force. If two magnets are brought into the neighbourhood of one another they tend to arrange themselves so that their lines of force assume the same direction where they overlap. If a magnetic needle is suspended it sets itself north and south, so that its own lines of force—the majority of which lie between its two poles—may coincide with those of the earth.

It has been mentioned that a wire along which a current is flowing is surrounded by a magnetic field. The lines of force have a definite direction. They are arranged concentrically around the wire conveying the current, in a plane at right angles to it. If a magnetic needle is placed close to a wire along which a current is flowing, the north-south direction previously taken under the influence of the earth's magnetic lines is now altered by the new magnetic lines created by the current. The magnetic needle now alters its direction so that its own lines of force can coincide as far as possible with those created by the current. The position which the north-seeking pole of the needle will assume can be foretold if the following illustration is remembered :—

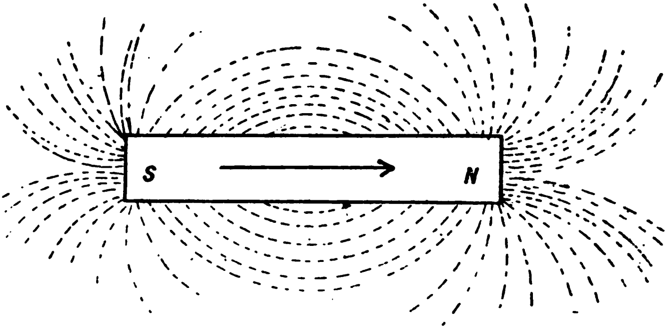


FIG. 73.—Lines of Force around a Bar Magnet.

Imagine a man swimming in the wire in the same direction as the current and turned so as to face the needle, then the north-seeking pole of the latter will be deflected towards his *left* hand.

The Galvanometer.—This is an instrument designed for the measurement of electrical currents. An *amperemeter* (or ammeter) is a galvanometer graduated so as to indicate on its scale the number of amperes passing though it. A milliamperemeter indicates the current in thousands of an ampere, 1 milliampere being 1/1000th of an ampere.

A *voltmeter* is a galvanometer that measures electro-motive force.

These instruments work on the principles described above; the current causes the deflection of a movable magnetic needle, and the amount of deflection is the measure of the strength of the current.

Until comparatively recently, all galvanometers were of the magnetic needle type. While undoubtedly accurate, they laboured under certain disadvantages. They had to be carefully levelled, and placed in proper relation to the magnetic meridian to bring the pointer to zero. The latter always took some time to come to rest, and the readings were easily disturbed by the presence of magnetic bodies near by. It is not necessary to refer to them further, as they have been displaced by instruments of the " moving coil " type, one of which is shown in Fig. 74.

Whereas in the original form of instrument the magnetic needle was movable and the wire conveying the current stationary, in the moving-coil form the reverse arrangement is seen. The magnet—which is U-shaped—is stationary, and between its poles is the coil of wire that conveys the current. This coil is movable and an indicator is attached to it that moves over a scale calibrated to indicate the number of milliamperes.

These instruments read accurately in any position, are quite independent of the earth's magnetism or the presence of magnetic bodies, and they are "dead beat"—that is to say, the pointer quickly indicates the amount of current passing, without first swinging to and fro for some time. The instrument showing the scale reads to 15 milliamperes. As this current is too small for some purposes, the instrument is provided with one or more shunts, which can be switched on or off as desired. By means of the shunts, the instrument can measure considerably greater currents. The principle of the shunt is that when a current has two paths in which to flow, it divides itself between the two, so that the current strengh in each path is inversely proportional to its resistance. The arrangement is shown diagrammatically in Fig. 75.

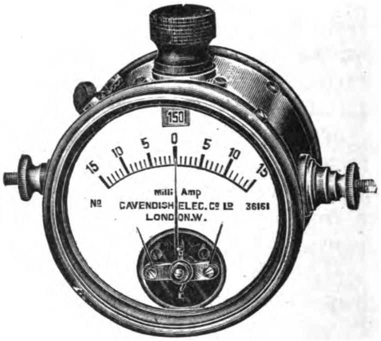


FIG. 74.—Milliamperemeter of the "Moving Coil" Type.

As there shown, all the current that passes through the instrument will flow through the coil which causes the needle to move. The resistance of the shunt marked 10 is so adjusted that when it is brought into circuit 9/10 of the total current passes through it, and 1/10 through the coil controlling the needle. Therefore the total current passing will be ten times that indicated by the instrument. If the other shunt is used the readings are to be multiplied by 100. The knob on the top of Fig. 74 is for switching the shunts in or out of circuit. As it is revolved, the figures 1, 10, 100 pass in succession behind a small opening in the top of the dial, indicating which shunt is in circuit. In some instruments, however, the figures indicate the maximum current recorded when that particular shunt is in circuit. In the instrument shown in Fig. 74, the number 150 is shown, and it means that the instrument now records between zero and 150 milliamperes. When the zero is showing it means that the whole instrument is out of action. In this position it is impossible for the instrument to be injured by the accidental passage of a heavy current through it, which would probably cause serious, if not irreparable, damage.

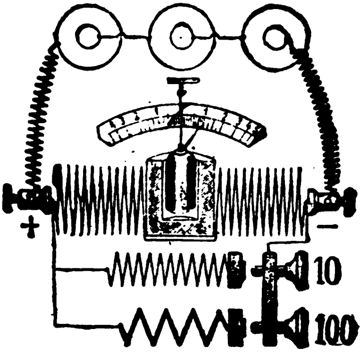


Fig. 75.—Arrangement of Shunts in Milliamperemeter.

To measure *alternating* currents, a special form of amperemeter is required. It is composed of a fixed wire spiral and a movable soft iron rod which is placed at one end of the spiral and just outside it, so that the long axes of both are continuous. The alternating current passes along the spiral and induces magnetism in the iron rod. The magnetism induced in that end of the rod which is nearest to the spiral will always be of the opposite variety to that of the field around the end of the spiral nearest to the rod. Consequently the rod will always be drawn further into the spiral and the amount of its movement will be a measure of the strength of the current flowing along the spiral.

The Electro-Magnet.—It was shown that a wire carrying an electric current became magnetic and would attract iron filings. If we take a piece of soft iron rod and wrap this wire around it, it will impart its magnetism to the iron, which will become strongly magnetic, especially if the wire is wrapped many times round and a strong current sent through it. This arrangement constitutes an "electro-magnet." An electro-magnet is only magnetic when an electric current is traversing its wire helix, provided the core —as it is called—is composed of *soft* iron or *soft* steel. Magnets on this principle can be made capable of lifting many tons' weight. They lose their magnetism entirely when the current is cut off. If the core should be made of very hard steel, a portion of the magnetism remains after the current is cut off. This core may be removed from the centre of the wire winding, and will retain more or less of its magnetism indefinitely. In this way permanent magnets are made.

Electro-Magnetic Induction.—The first observations of this most interesting and important subject were made by Faraday. He found that in a closed circuit an electric current of momentary duration is induced when a magnet is approached to this conductor or withdrawn from it. He also found that if a current were made to pass through another circuit near, but quite detached from, the first one, a momentary current passed through the latter, both when the current started and when it was interrupted. The current is produced by virtue of the magnetic field set up and removed in the neighbourhood of the original closed circuit. These induced currents, as they are called, only appear so long as the magnetic field is varying in strength. The current induced at the starting of the inducing current is in an opposite direction to the latter, while that produced when the inducing current is interrupted is in the *same* direction as the inducing current. It will thus be seen that whether we use a permanent magnet, an electro-magnet or a length or a coil of wire a closed circuit to a varying field of magnetic force, currents of electricity are set up in the closed circuit. These currents will vary in direction of flow according as the magnetic field is increasing or decreasing in strength.

Simple as the fundamental principle of the induction of currents is, it is perhaps the most important of all as regards the practical applications of electricity. The dynamo, motor, induction coil, telephone, etc., are all based on the principle of electro-magnetic induction.

Self-Induction.—Take a length of insulated copper wire, say two or three yards, straighten it out and attach one end to one terminal of a cell possessing high internal resistance, such as a Leclanché cell. Bring round the other end (both ends must be stripped of their insulating covering for an inch or so) and touch the other terminal of the cell with it for a moment. A very tiny spark will be seen at the instant the wire leaves the terminal. It may be necessary to do this experiment in a darkened room, so small is the spark.

Now coil up this length of wire into a close spiral by winding it on a ruler, and repeat the experiment. At the moment when the circuit is broken and the current ceases to flow, a spark that is distinctly brighter will be seen at the point where the circuit is interrupted. This is the result of the induction of new currents in the turns of the spiral at the moment the original current ceases to flow. These new currents flow in the *same* direction as the latter, and so reinforce it. A brighter spark is therefore produced. At the moment when the circuit is *completed,* new currents are again induced, but these flow in a direction *opposite* to that of the original current, and so weaken it. The weakening is only momentary, because the induced currents flow only for a moment, and therefore all that they do is to retard the rise of the original current to its full strength while they are flowing.

The development of induced currents *in the same circuit*, as that in which the inducing current is flowing, is spoken of as "Self-Induction." If we introduce a rod of iron into the spiral, and the experiments are repeated, the effects described above will be further increased. Stronger currents will be induced at make and at break of the circuit and will further weaken the inducing currents at make and further reinforce it at break.

We can vary the amount of this self-induced current by increasing or decreasing the number of turns in the spiral, by varying the strength of the original current, and by inserting or withdrawing an iron core.

The Alternating Current.—The current of which we have been speaking up to the present is the constant current, the current that is flowing continuously, always in the same direction, and with strength unvaried. An alternating current is one that is constantly reversing its direction of flow. The reversals may be rhythmic or arrhythmic, regular or irregular, frequent or infrequent. Fig. 9 (page 26) is a graphic representation of an alternating current of which the reversals are rhythmic, regular, and frequent. When an alternating current is spoken of without further qualification it is usually understood to be of the type represented in the figure. From *A* to *B* the current rises from zero to its maximum; from *B* to *C* it falls again to zero. From *C* to *D* the current again rises from zero to maximum; from *D* to *E* it falls again to zero. From *C* to *E* the current is flowing in the opposite direction. The complete course, from *A* to *E*, is spoken of as one complete cycle or phase. The height of the curve above the base line at any one spot is proportional to the voltage and the length along it to the time intervals. This alternating current is produced by a dynamo, and it will be seen in the next paragraph how it is generated. These currents are frequently named "sinusoidal," because their graphic representation is approximately a sine curve. In many districts the town supply is an alternating current (AC). In others it is a constant or "direct" current (DC).

The Production of Alternating Currents.—When a coil of wire is made to revolve in a magnetic field an electrical current will flow round the coil. On this principle currents are generated by the dynamo.

Fig. 76 is a simple diagram which will show how the alternating current, graphically represented in Fig. 9, is produced. The two poles of a magnet are shown, and between them is a single coil of wire. When the coil revolves it cuts across the magnetic lines of force which pass between the opposite poles of the magnet. An E.M.F. is thereby produced and, if the circuit is complete, a current flows. During its rotation, when it is in the position shown in the figure (*A*), equidistant from both poles, no current flows around it, because it is not cutting across the lines of magnetic force. During its rotation through a right angle (one quarter of a complete revolution) a current flows around it, starting from zero, its strength gradually increasing and attaining its maximum value when the coil has the position shown in Fig. 76 (*B*). During this quarter revolution, the coil has cut across the magnetic lines at a gradually increasing angle. During the next quarter of a revolution the current gradually falls again to zero, the lines having been cut across at a gradually diminishing angle, until, when the coil is equidistant between the poles, the lines are not cut across and no current flows. During the third quarter the current again increases to a maximum, and during the fourth quarter it gradually reaches zero again. The current that flows during the last two quarters of the revolution is in the reverse direction. For the first half of the revolution the current is in one direction; for the second half it is in the opposite direction. During each half it starts from zero, reaches a maximum and again falls to zero. This current is the alternating

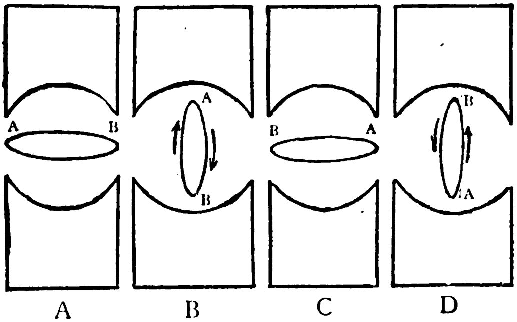


FIG. 76.—To illustrate way in which an Alternating Sinusoidal Current is produced.

current described in the previous paragraph, and it may be graphically represented as in Fig. 9. The curve shown, *ABCDE*, corresponds to one complete revolution of the coil. The "frequency" or "periodicity" of an alternating current refers to the number of these complete revolutions per second. Thus if the periodicity of the current is 100, the coil is revolving 100 times per second; the length of the curve recording one complete cycle would be 1/100th of a second, and there would be 200 reversals of direction (or alternation) each second. The curent is called "sinusoidal" because its strength at any moment is proportional (approximately) to the sine of the angle at which the coil, at that moment, cuts the lines of force. In the positions A and C (Fig. 76), the coil is not cutting any lines and no current is flowing. In the positions B and D, the coil is cutting the lines at right angles, and the maximum current is flowing. To collect the current from the coil, the following device is used. A couple of metal rings are mounted concentrically on the axle to which the coil is attached (not shown in the figure). These rings are placed side by side, without touching. They are insulated from each other and from the axle. The free ends of the wire of the coil are attached to these rings. A carbon rod or metal brush makes contact with each ring. These collecting rods or brushes deliver the current where desired. The metal rings are known as "slip rings."

To make the current unidirectional, another form of collecting device is used. A single metal ring is used but it is divided transversely into two halves, at opposite ends of the same diameter. The two halves are insulated from each other and from the axle. Both carbon rods make contact with the ring but at opposite ends of the same diameter. When the coil is in the position equidistant between the poles (A and C, Fig. 76), the carbon rods are touching the divided ends of the ring; each half of the ring is leaving one carbon and about to make contact with the opposite carbon.

The current delivered by the carbons is now, not alternating, but uni-directional. Its graphic record would be like that shown in Fig. 9, but with the second half of the curve on the same side of the base line as the first half. Such a current would be, not constant, but intermittent.

To make it constant (or as nearly constant as is possible in a dynamo) several coils separate from each other are used.

The slip ring is divided into several portions so that the ends of each coil is connected to a portion of the divided ring.

Now when any coil is in the position shown at *B* (Fig. 76) it is delivering its maximum current to those divisions of the ring with which it is in contact. In this position the carbon rods are making contact with those divisions. When the coil has moved on and the current is just beginning to diminish, the division of the ring leave contact with the carbon rods. At this moment the next coil is brought into contact with the carbon rods and this coil now delivers its current to the rods. As each coil passes successively into the position *B* (Fig. 76) it delivers its current and makes way for the next coil. If the body is placed in a circuit connecting these carbon rods it receives a current which is not absolutely constant, but slightly undulatory. The larger the number of coils the more finely undulatory is the current. An absolutely constant current like that obtained from a cell cannot be obtained from a dynamo.

The account given above describes the principle on which alternating and direct currents are obtained from a dynamo.

An actual dynamo, in a very simple form, will be described in the next paragraph. Small dynamos are fitted to the " Universal " apparatus which has been mentioned on many occasions in the preceding pages (Fig. 10).

The Dynamo.—It may be said that over 99% of the electricity used for various purposes is obtained from dynamos. By far the most convenient source of electricity for medical purposes is the dynamo at the power station, from which the supply is taken along the mains to the places where it is desired. In places where there is no main supply, the current may be derived from a small dynamo worked by a gas or oil engine or by water-power.

A dynamo consists of three essential parts: (1) the field magnet; (2) the armature; (3) the current-collecting device (Fig. 77).

(1) *The Field Magnet,* which generally forms part of the framework of the machine, is usually an electro-magnet, the poles of which have their opposing faces hollowed out to the arc of a circle, in which space the armature revolves. When the field magnet is excited this space will be the seat of a powerful magnetic field. The essential point about the field magnet is that its poles never change; one is always north and the other south.

(2) *The Armature* is the part of the dynamo in which the current is induced by reason of its movement in the magnetic field. In the simple device shown in Fig. 76 it was a single circuit of wire. The armature of a dynamo that generates alternating currents consists of an axle surrounded by strips of soft iron, upon which are wound several turns of insulated copper wire. The free ends of this wire are connected to the slip rings of the current collector.

The armature of a dynamo that is to generate a current that flows in the same direction and with constant strength (the constant current, or direct current) contains several separate coils.

(3) *The Current-Collecting Device.*—If an alternating current is to be collected the device consists of two metal rings mounted concentrically on the axle of the armature. They are insulated from each other and the axle. To one of them is fixed one of the free ends of the wire wound round the armature. To the other ring is fixed the other free end. A metal spring presses against each ring and leads the current to the main circuit. As the axle of the armature revolves, the rings revolve with it, and the springs collect the current from the rings. The current collected is an alternating current.

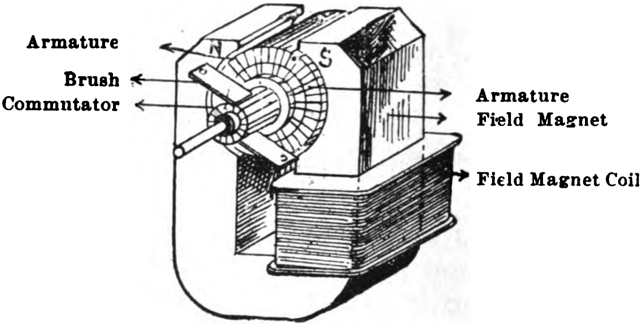


FIG. 77.—Dynamo constructed to generate a Direct Current.

If a constant (direct) current is to be collected the collecting device (called in this case a "commutator") consists of a number of copper bars mounted in the form of a cylinder, and insulated from the shaft and from each other. There are as many bars as there are coils on the armature. The beginning of one coil and the end of the coil just preceding it are joined together, and the two are attached to a commutator bar. Two brushes of copper gauze or carbon press against the revolving cylinder and collect the current (see Fig. 77).

Dynamos and Motors: Motor Generators.—The dynamo that generates a *direct* current is a reversible machine. That is to say, if another direct current is sent through the armature, the latter will revolve. The dynamo, therefore, now acts as a motor, converting electrical into mechanical energy. Motors are also constructed so as to work when supplied by an alternating current. Electric motors are used in medicine for several purposes, for working drills and trephines, for applying massage and vibration, etc.

Electric motors are used for another purpose. They can be used to work dynamos constructed to generate a new current separate from that which works the motor. A combination of a motor and dynamo for this purpose is called a "motor generator." A motor generator is an exceedingly useful machine and is extensively used now in electro-medical work. The new current is on an independent circuit and there are no earth connections. The circuit is therefore "earth-free," and a patient included in it is in no danger of shocks when he touches earthed objects. Motor generators are fitted to the various models of "Universal" apparatus. In one of these, the "Pantostat" (Fig. 10) the dynamo and motor are separate from each other. In others the field magnets are the same, both for motor and dynamo, and the armature is wound with two separate coils. One of these belongs to the motor side of the armature and is traversed by the current from the main. The other belongs to the dynamo side and yields the new current. The two coils are carefully insulated from each other.

If the main current is *direct,* and a sinusoidal alternating current is desired, another coil could be wound on the armature and connected to slip rings. But it is possible to derive a sinusoidal alternating current from the motor side of the armature. It has already been mentioned that a motor and dynamo are identical in construction. If any two diametrically opposite bars of the commutator are connected to slip rings, the coil which is connected to these bars will deliver a sinusoidal alternating current to the slip rings when the armature is made to revolve. The revolution can be effected mechanically or by the current from the main. This sinusoidal current is not earth-free. To make it so, it is passed through the primary coil of a static transformer. It induces a new sinusoidal current in the secondary coil and this new current is earth-free. In the " Universal " apparatus there are three separate secondary coils. The winding of these is arranged so that the voltage and amperage of the induced currents is suitable, in the current from one coil, for passing through the body; in the current from the second coil, for illuminating exploring lamps; in the current from the third coil, for heating cautery instruments.

When the current from the main is alternating, the current for the three purposes mentioned can be obtained from a static transformer. It is only for the production of a *direct* current that a combined motor and dynamo are required.

Static Transformer.—A motor transformer can be used for the purpose of converting an *alternating* current into another *alternating* current with a different voltage and amperage, but a much more efficient and less costly apparatus for the purpose is the " static transformer." It is called a *static* transformer because there are no moving parts. It consists of a core of soft wire made in the form of a ring or a square (Fig. 78). A coil of insulated wire is wound around one side. Another independent coil, also of insulated wire, is wound on the opposite side. The alternating current is led through one of these coils. As it alternates backwards and forwards a varying magnetic field is set up in the core; as a result, new alternating currents are induced in the other coil. The latter coil is known as the secondary coil, to distinguish it from the other coil, which is known as the primary coil. The voltage and amperage of the current that is induced in this secondary coil depends on the number of turns it contains as compared with the number of the primary. To take an example. Suppose that the primary coil has 100 turns of wire supplied

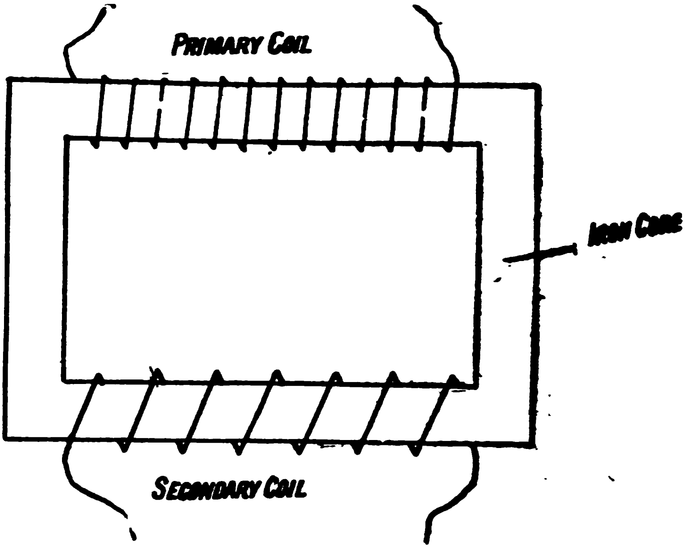


FIG. 78.—Plan of a Static Transformer.

by alternating current of one ampere at a pressure of 100 volts, and that we wish to obtain a current to heat a cautery which requires a pressure of, say, 5 volts. If the secondary coil is wound with 5 turns of wire, the voltage of the current in this coil will be lowered to 5, while the amperage will be raised to 20. This combination of voltage and amperage is suitable for the cautery. If there were 1,000 turns on the secondary coil the voltage of the current in the latter coil would be 1,000 and the amperage would be 1/10. These figures are theoretically correct, and assume that there is no loss of energy in the transformation. As a matter of fact, there is some loss of energy, but it is very small, and a well-designed transformer gives out from the secondary coil very nearly the same amount of energy as is supplied to the primary.

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